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BROCHANTITE

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ABSTRACT

Brochantite is proved by crystallographic, x-ray, and optical study to be monoclinic. The common orthorhombic pseudosymmetry is due to twinning on (100). New elements and many new forms are presented in the new monoclinic position. Crystals described by earlier authors are analyzed with reference to the monoclinic setting.

The symmetry of brochantite has been in doubt since Schrauf (1873) published his monograph on the species. Originally described as orthorhombic by Levy (1824), there is no doubt that the vast majority of crystals hitherto studied are at least pseudo-orthorhombic in appearance. Schrauf concluded from his usual careful measurements that his crystals were either monoclinic or even triclinic with but slight deviation from orthorhombic symmetry, and that their pseudosymmetry was due to complex twinning on one or more of several laws. His stated failure to find optical confirmation of this conclusion was not regarded by him as a valid objection. No other student of the species except his colleague Brezina could verify Schrauf's findings, and brochantite appears in modern descriptions as orthorhombic with an expressed doubt as to its true symmetry. Goldschmidt (1897) with good right explains this lasting uncertainty as due to the poor quality of the crystals studied.

The writer approached the study of brochantite in an attempt to discover whether or not antlerite* had been mistaken for it in other cases than that at Chuquicamata (Palache and Warren, 1908, emended by Ungemach, 1924). New material was at hand for the study, in part already examined by Dr. Foshag of the U. S. National Museum, who had measured crystals of undoubted monoclinic symmetry and kindly loaned his crystals for this investigation. The new specimens were from the Shattuck Mine, Bisbee, Arizona. They consist of a number of masses of loosely coherent aggregates of coarse prismatic crystals of the usual type, in the interstices of which well-terminated crystals could be found. These were of two habits:— slender prisms with complex terminations; and short, tabular crystals of minute size and perfect quality always implanted on the surface of the earlier prismatic crystals. Crys-

* Compare the paper on Antlerite by the author, *Am. Mineral.*, 24, 293-302, 1939.

tals of both habits showed individuals of well-marked monoclinic development, and also twins on the orthopinacoid {100}, which were pseudo-orthorhombic. The tabular crystals were frequently doubly terminated and so clear-cut and perfectly developed that their study left no doubt of their truly monoclinic character. The outcome of the morphologic, x-ray and optical examination is to compel the belief that brochantite is monoclinic but in a sense wholly different from Schrauf's interpretation, and that its pseudo-orthorhombic appearance is the result of almost universally present twinning. The presentation of the new data of observation will be followed by a brief review of previously described crystals in the light of the new interpretation.

BROCHANTITE FROM THE SHATTUCK MINE, BISBEE, ARIZONA

Type one, prismatic crystals. The crystals range from needles of extreme slenderness to stout prisms. All tend to be striated in the prism zone and the larger ones are apt to be subparallel aggregates. All are attached at one extremity and many have all the appearance of being simple individuals. Figures 1 and 2 show typical illustrations of this type, the first pseudo-orthorhombic, the second monoclinic. It is evident, however, on consulting the figures that the first may be interpreted as a symmetrical twin-group of two individuals like the second, with {100} as twinning plane. The cleavage, always previously orientated as brachypinacoidal, is parallel to the twinning plane and normal to the single plane of symmetry. It becomes therefore {100} in the monoclinic setting. Since no crystal of this type was found doubly terminated, there was no possibility of proving the presence of twinning by the observation of a re-entrant angle. The forms present are discussed below.

Type two, tabular crystals. These crystals were first found loose among the debris of prismatic crystals when a cavity had been opened. Later they were found in no small number, lightly attached to the surfaces of crystals of the dominant habit. Rarely more than a millimeter in maximum diameter, and of so consistent a monoclinic habit, they were at first supposed to be of another mineral; but measurement and optical character identified them as certainly brochantite. Figures 3 and 4 illustrate their appearance, the first an individual, the second a twin. The drawings faithfully reproduce the perfect regularity of these crystals. The twin shown in Fig. 4b was mounted by Dr. Berman for optical examination with the twin plane vertical. The two members of the twin showed a distinct optical discontinuity; so slight, however, was the deviation of the position of extinction of each from the common cleavage and twin plane {100} that Dr. Berman hesitated to evaluate an extinction

angle, although he was convinced that the discontinuity existed. The optical orientation is indicated in Fig. 34. The cleavage {100} is so perfect that most grain mounts show only cleavage flakes, and therefore twinning is not ordinarily observable.

Crystal Measurements. Upwards of thirty crystals were measured with concordant results, as may be seen from Table 1. Here are shown the angles of the seven untwinned crystals only. They agree well with the general average collected from measurements of sixteen crystals, twinned and untwinned.

TABLE 1. BROCHANTITE: MEASURED ANGLES OF SEVEN UNTWINNED CRYSTALS.

Forms	No. of faces	Mean		Range		Calculated	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
<i>c</i> 001	9	90°00'	13°21'	90°00'–90°09'	13°17'–13°26'	90°00'	13°21'
<i>a</i> 100	3	90 09	90 00	90 00–90 27	—	90 00	90 00
<i>l</i> 120	2	21 17½	90 00	21 13–21 22	—	21 09	90 00
<i>m</i> 110	16	37 47	90 00	37 29–37 57	—	37 44	90 00
<i>d</i> 210	13	57 01	90 00	56 49–57 13	—	57 08	90 00
<i>p</i> 011	7	21 04	33 23	20 35–21 26	33 15–33 34	21 09	33 20½
<i>q</i> 021	1	10 36	51 18	—	—	10 57	51 20
<i>r</i> 031	3	7 29	61 40	7 19–7 43	61 31–61 48	7 21	61 41
<i>z</i> 104	2	90 00	19 36	—	19 33–19 40	90 00	19 36
<i>y</i> 201	4	90 00	49 46	—	49 40–49 51	90 00	49 53
<i>x</i> 704	1	–90 00	30 38	—	—	–90 00	30 41
ξ 201	1	–90 00	35 17	—	—	–90 00	35 27
<i>P</i> 111	6	49 10	43 16	48 55–49 32	43 00–44 00	49 15	43 13½
π 111	6	–21 10	33 27	20 47–21 33	33 18–33 33	–21 09	33 20½
<i>B</i> 211	4	62 32	53 10	62 14–62 41	53 00–53 18	62 40	53 11
β 211	3	–49 25	43 19	49 10–49 47	43 15–43 27	–49 15	43 13½
Ψ 131	2	–7 09	61 42	–6 56–7 22	61 34–61 50	–7 21	61 41

One hundred faces of twelve forms were used to calculate new elements, which seem to be definitely more reliable than those of Koksharov. The calculation was made for the orthorhombic position and the results compare as shown below with other elements used.

	<i>a</i> : <i>b</i> : <i>c</i>
Koksharov	0.7739:1:0.4871
Goldschmidt (mean of 3)	0.7777:1:0.4906
Palache	0.7738:1:0.4747

The monoclinic position requires the following equivalent forms:—

Orthorhombic	Monoclinic
001	$\bar{1}02$
100	010
$0\bar{1}0$	100
$0\bar{1}2$	001
$2\bar{1}2$	011

Transformation formulae:—

Orthorhombic to Monoclinic $0\bar{1}\frac{1}{2}/100/001$

Monoclinic to Orthorhombic $010/\bar{1}0\frac{1}{2}/001$

The elements as given above, transformed to the monoclinic position, become $a:b:c=1.3283:1:0.6135$; $\beta=103^\circ 21'$. From these elements was calculated the new angle table shown in Table 2.

TABLE 2. BROCHANTITE: ANGLE TABLE.

Brochantite— $\text{Cu}_4(\text{SO}_4)(\text{OH})_6$

Monoclinic; prismatic— $2/m$

$a:b:c=1.3283:1:0.6135$; $\beta=103^\circ 21'$

$p_0:q_0:r_0=0.4619:0.5969:1$; $\mu=76^\circ 39'$

$r_2:p_2:q_2=1.6753:0.7738:1$;

$p'_0=0.4747$, $q'_0=0.6135$; $x'_0=0.2373^5$

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A	Orth.
<i>c</i> 001	90°00'	13°21'	76°39'	90°00'	—	76°39'	<i>e</i> $0\bar{1}2$
<i>b</i> 010	0 00	90 00	—	0 00	90°00'	90 00	<i>a</i> 100
<i>a</i> 100	90 00	90 00	0 00	90 00	76 39	—	<i>b</i> $0\bar{1}0$
<i>E</i> 140	10 57	90 00	0 00	10 57	87 29	79 03	4 $\bar{1}0$
<i>l</i> 120	21 09	90 00	0 00	21 09	85 13½	68 51	* 2 $\bar{1}0$
<i>m</i> 110	37 44	90 00	0 00	37 44	81 52½	52 16	<i>h, m</i> $1\bar{1}0$
<i>n</i> 430	45 53½	90 00	0 00	45 53½	80 27½	44 06½	<i>n</i> 340
<i>d</i> 210	57 08	90 00	0 00	57 08	78 49	32 52	<i>d</i> 120
<i>F</i> 410	72 05½	90 00	0 00	72 05½	77 18½	17 54½	140
<i>o</i> 012	37 44	21 12	76 39	73 23	16 37	77 13	<i>o</i> $1\bar{1}2$
<i>p</i> 011	21 09	33 20½	76 39	59 10	30 50	78 34	<i>p</i> $2\bar{1}2$
<i>q</i> 021	10 57	51 20	76 39	39 57	50 03	81 28½	* 4 $\bar{1}2$
<i>r</i> 031	7 21	61 41	76 39	29 11	60 49	83 32	* 6 $\bar{1}2$
<i>z</i> 104	90 00	19 36	70 24	90 00	6 15	70 24	* 034
<i>i</i> 102	90 00	25 23½	64 36½	90 00	12 02½	64 36½	<i>i</i> $0\bar{1}1$
<i>u</i> 304	90 00	30 41	59 19	90 00	17 20	59 19	* 054
<i>y</i> 201	90 00	49 53	40 07	90 00	36 32	40 07	* 052
γ 702	90 00	62 13½	27 46½	90 00	48 52½	27 46½	γ $0\bar{4}1$
δ $\bar{1}02$	—90 00	0 00	90 00	90 00	13 21	90 00	<i>c</i> 001
ϵ $\bar{1}01$	—90 00	13 21	103 21	90 00	26 42	103 21	<i>e</i> 012
x 704	—90 00	30 41	120 41	90 00	44 01	120 41	* 054

TABLE 2. (Continued)

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A	Orth.
ξ 201	-90 00	35 27	125 27	90 00	48 48	125 27	* 032
θ 301	-90 00	49 53	139 53	90 00	63 14	139 53	* 052
ν 401	-90 00	58 57 $\frac{1}{2}$	148 57 $\frac{1}{2}$	90 00	72 18 $\frac{1}{2}$	148 57 $\frac{1}{2}$	* 072
P 111	49 15	43 13 $\frac{1}{2}$	54 33	63 27	34 01 $\frac{1}{2}$	58 44 $\frac{1}{2}$	* 232
π 111	-21 09	33 20 $\frac{1}{2}$	103 21	59 10	39 54 $\frac{1}{2}$	101 26	p 212
Σ 331	-32 49	65 27 $\frac{1}{2}$	139 53	40 08	73 07	119 32	* 652
A 162	14 27 $\frac{1}{2}$	62 15	64 36 $\frac{1}{2}$	31 01 $\frac{1}{2}$	59 43 $\frac{1}{2}$	77 14	* 311
V 122	0 00	31 32	90 00	58 28	33 58	90 00	v 101
x 142	0 00	50 49	90 00	39 11	52 04	90 00	x 201
α 162	0 00	61 29	90 00	28 31	62 19 $\frac{1}{2}$	90 00	* 301
t 252	24 54	59 24	54 33	38 40 $\frac{1}{2}$	54 37	68 45	t 532
ω 212	-37 44	21 12	103 21	73 23	31 07 $\frac{1}{2}$	102 47	o 112
Ψ 131	- 7 21	61 41	103 21	29 11	64 10 $\frac{1}{2}$	96 28	* 612
B 211	62 40	53 11	40 07	68 26	41 39	44 40	* 252
β 211	-49 15	43 13 $\frac{1}{2}$	125 27	63 27	53 54	121 15 $\frac{1}{2}$	* 232
Δ 11.4.4	-60 07 $\frac{1}{2}$	50 55 $\frac{1}{2}$	136 53	67 15	62 45	132 19	* 494
Φ 311	-62 40	53 11	139 53	68 26	65 14 $\frac{1}{2}$	135 20	* 252

* New Forms.

Figure 33 represents a gnomonic projection based upon this angle table. It presents features which seem to call for comment.

The projection of a monoclinic crystal can approach orthorhombic symmetry in either of two ways: if the angle β is nearly or exactly 90° (case of humite), the projection of $\{001\}$ falls nearly or exactly in the center of the projection; but the center of the projection also becomes a point on the lattice if the relation of μ and $p_0'^1$ is such that $\cot \mu = x_0' = \frac{1}{2} p_0'$. That is exactly the case in the projection of brochantite, as may be seen by inspection. It is nearly true in some other monoclinic species, such as orthoclase, diopside, hornblende and colemanite. This leads, of course, to difficulty in recognizing from the projection the true symmetry of the crystal represented. It also leads, in some instances, to pairs of forms, positive and negative respectively, such as γ and θ , p and π , P and β , etc., which have identical ρ angles and ϕ angles differing only in sign. These pairs in the case of the projection of brochantite are

$$^1 p_0' = \frac{c}{a \sin \beta}.$$

the equivalents respectively of pairs or groups of faces of what were in the orthorhombic interpretation a single form. If this projection is viewed from the direction of the b axis it is, as regards dimensions, a true presentation of *orthorhombic* brochantite; the extent to which face-poles to the right and the left of the median line fail to be symmetrically present reflects the actual observations made upon indubitably monoclinic crystals.

It is, of course, also true that twinning on $\{100\}$ may have the effect of producing full orthorhombic symmetry in the projection. Since, unless the crystal is doubly terminated, there is no sure way of recognizing the presence of twinning in brochantite, it was concluded that only those forms should be listed in the monoclinic interpretation which had actually been observed on crystals either simple or unequivocally twinned.

In Table 3 may be found a tabulation of the combinations studied. Many of these are also shown in the numerous figures of Plates I and II. The dominant habit is prismatic on $[001]$; but elongation on $[010]$ and more rarely on $[100]$ was also found. The forms most commonly developed are comparatively few. $c\{001\}$ is rarely absent, but its correlative form $\epsilon\{\bar{1}01\}$ was seen but twice. The prism zone rarely fails to show all three of the forms $a\{100\}$, $m\{110\}$ and $d\{210\}$. $p\{011\}$ and $\pi\{\bar{1}11\}$ are rarely lacking; together they are the equivalent of the orthorhombic pyramid $p\{212\}$, which was the only common and well-established pyramid form previously known. $\gamma\{201\}$, $v\{\bar{1}22\}$ and $B\{211\}$ are also common forms.

TABLE 3. BROCHANTITE: COMBINATIONS OF FORMS ON CRYSTALS STUDIED.

Crystal	Bisbee													Algiers	Tsumeb	Chile A	Chile B	Cornwall	Frisco 1	Frisco 2	Tintic 1	Tintic 2	Vasko										
	1	2	3	4	5	6	7	8	9	10	11	12	13											17	18	19	21	22	23	24	25	26	29
<i>c</i> 001	x	x	x		x	x	x	x	x	x	x	x	x				x	x	x	x													
<i>b</i> 010	x	x	x	x				x	x	x	x	x	x	x				x	x	x													
<i>a</i> 100				x					x	x	x	x	x	x																			
<i>l</i> 120		x	x	x	x		x	x	x	x	x	x	x	x				x															
<i>m</i> 110	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x															
<i>d</i> 210	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x															
<i>p</i> 011					x	x	x	x	x									x															
<i>q</i> 021											x	x	x																				
<i>r</i> 031				x			x																										
<i>s</i> 104											x																						
<i>t</i> 102										x	x																						
<i>u</i> 304																																	
<i>y</i> 201					x			x	x	x																							
<i>o</i> 102	x																																
<i>e</i> 101																																	
<i>x</i> 704																																	
<i>z</i> 201																																	
<i>θ</i> 301																																	
<i>r</i> 101																																	
<i>π</i> 111	x				x		x	x	x	x	x	x	x	x																			
<i>σ</i> 331																																	
<i>4</i> 162																																	
<i>17</i> 122																																	
<i>α</i> 162	x	x	x	x	x																												
<i>ω</i> 212	x	x	x	x	x																												
<i>ψ</i> 131																																	
<i>B</i> 211																																	
<i>β</i> 211																																	
<i>Δ</i> 11.4.4																																	
<i>Φ</i> 311																																	
Twin figure	2				x	T		3		9				x	x	x	6	7	$\frac{x}{T}$	5	10	4	8	11	12	13	14	15	16	17	18	19	20

The angle table contains a number of forms equivalent to forms unknown to orthorhombic brochantite. These new forms are collected together with the determining angles in Table 4.

TABLE 4. BROCHANTITE: MEASUREMENTS OF NEW FORMS.

		Mean		Range		No.	Qual.	Orth.
		ϕ	ρ	ϕ	ρ			
<i>l</i>	120	21°14'	90°00'	20°51'–21°31'	—	10	fair	210
<i>q</i>	021	10 50	51 20	—	—	1	good	412
<i>r</i>	031	7 11	61 41	7 02 – 7 19	61°34'–61°50'	5	good	612
<i>z</i>	104	88 52	20 16	88 11 –90 00	19 40 –20 33	4	poor	034
<i>u</i>	304	90 00	29 54	—	—	1	excellent	054
<i>y</i>	201	90 00	49 46½	89 57 –90 00	49 18 –50 00	12	excellent	052
<i>x</i>	704	–90 00	30 38	—	—	1	poor	054
ξ	201	–89 43	35 17	89 27 –90 00	35 17 –35 18	2	excellent	032
θ	301	–88 35	49 40	—	—	1	poor	052
ν	401	–89 42	58 44	89 08 –89 59	58 00 –59 10	3	poor	072
<i>P</i>	111	49 14	43 14½	48 55 –49 32	43 07 –43 22	7	fair	232
Σ	331	–32 38	65 25	—	—	1	excellent	652
<i>A</i>	162	14 14	62 25	13 55 –15 00	61 57 –62 34	5	excellent	311
α	162	0 36	61 29	0 00 – 1 00	61 11 –61 43	4	poor	301
ψ	131	– 6 54	61 50	—	—	1	excellent	612
<i>B</i>	211	62 35	53 10	62 14 –62 48	52 54 –53 28	12	good	252
β	211	–49 24½	43 18	–49 04 –49 55	43 06 –43 27	7	poor	232
Δ II.4.4	–60 19	50 55	–50 55 –60 10	—	—	2	good	494
Φ	311	–62 35	53 02	–62 28 –62 46	52 48 –53 10	5	fair	252

The occurrence of these new forms on the crystals studied may be seen in Table 3. Many of them occur frequently and are certainly established. Those reported but once may perhaps be regarded as calling for confirmation, but they were not accepted without remeasurement in each case to make sure that each represents a distinct face. Most of them were confined in their occurrence to the Bisbee crystals.

Twinning. The almost universal presence of twinning on the orthopinacoid in brochantite must be related in a definite manner with its structure. At the request of the author, this matter was examined by Mr. Wolfe, who made the following report on it.

Twinning of brochantite on {100} produces a precise coincidence of lattice points of the twinned and untwinned individuals (within the

limits of measurement), but the crystal motif of one is reversed with respect to the other. This is a common form of twinning. When such coincidence of twinned lattices occurs, the probability of twinning, according to the theory of twinning of Friedel, is large. In terms of his theory, this twin law is a case of twinning by pseudo-reticular merohedry with an obliquity of $0^\circ \pm$ and an index of 1.

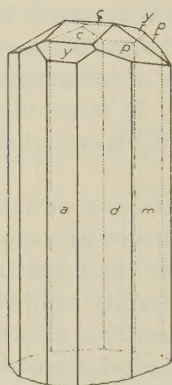
Although the limits of measurement do not indicate any deviation from twinning by reticular merohedry, the twinning must be by pseudo-reticular merohedry, since the former is not possible in the monoclinic system. The lattice row [201], consequently, must deviate somewhat from the normal to the twin plane, although the geometrical elements adopted indicate precise coincidence. (In the morphological description $\{\bar{1}02\}$ is precisely normal to [001].) Pseudo-reticular merohedry is further indicated by the planar rather than irregular nature of the composition surface.

Doubtful forms. Several forms reported by Schrauf seem highly doubtful for various reasons; most of them were described as measured on curved or imperfect faces. In the following list we have attempted to give a monoclinic interpretation of them.

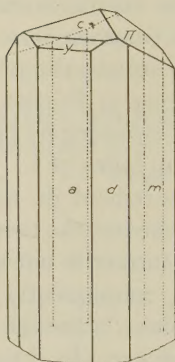
Schrauf	Monoclinic	
μ 730	370	probably vicinal to $\{120\}$
λ 610	160	described as having curved faces
f 616	233	very close in position to $\{I22\}$
g 313	$\bar{5}66$	probably vicinal to $\{I11\}$
s 136	$\bar{6}16$	close to $\{I01\}$
k 12.1.4	3.12.4	close to the common form $\{I62\}$. Compare Fig. 16, Pl. II. The faces of k are described as always curved.

$\rho\{1.16.0\}$ of Jeremejew is probably vicinal to $\{100\}$. $\{140\}$ and $\{410\}$ are prisms reported by Schoep (1927) and shown in our Fig. 32. He also found $\{340\}$ as did Biehl (1919) on a crystal from Tsumeb, which he did not figure.

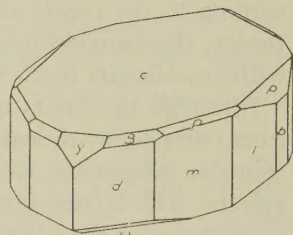
Many observations of single faces with poor reflections were made on our crystals but these forms, although mostly with simple indices, seemed too doubtful to record.



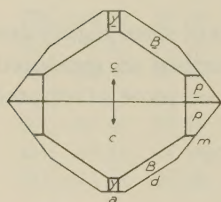
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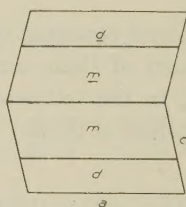
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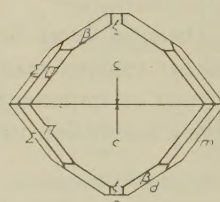
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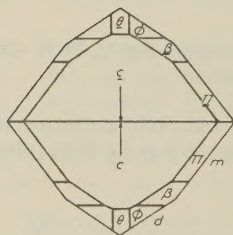
4a



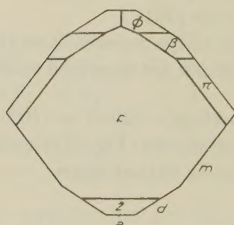
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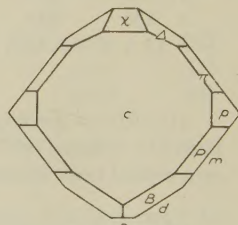
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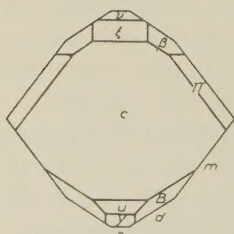
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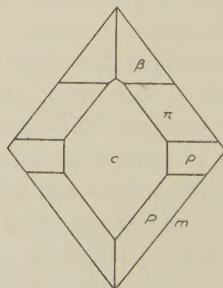
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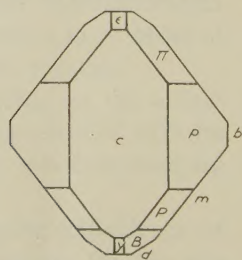
7



8



9



10

All crystals illustrated on this plate are from Bisbee, Arizona.

FIG. 1. Prismatic crystal, twinning on $\{100\}$. Pseudo-orthorhombic.

FIG. 2. Similar crystal, untwinned. No. 2 of Dr. Foshag.

FIG. 3. Tabular crystal (No. 8) doubly terminated. Such crystals sometimes show a fine twin-lamella traversing the basal pinacoid parallel to $\{100\}$.

FIGS. 4*a, b, c*. Doubly terminated twin crystal (No. 26).

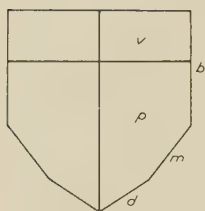
a. Top of crystal in plan; arrows show slope of basal planes.

b. Side elevation without truncating terminal planes.

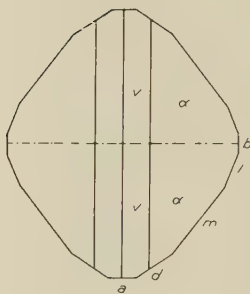
c. Bottom of crystal in plan.

FIG. 5. Twin crystal, doubly terminated, in plan.

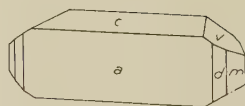
FIGS. 6, 7, 8, 9, and 10. Tabular crystals, each doubly terminated, in plan, showing various combinations of forms. All show pronounced monoclinic symmetry both in general form and especially in the varying distribution of the orthodome forms.



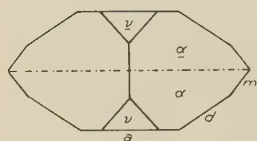
11



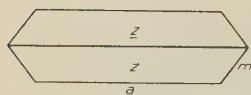
12



13



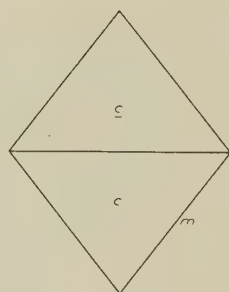
14



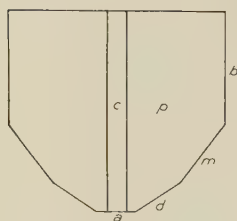
15



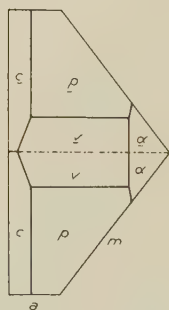
16



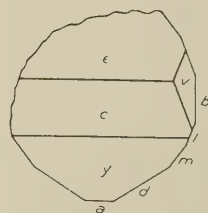
17



18



19



20

- FIG. 11. Bon Thaleb, Algeria (No. 88658). Plan of a thick, stubby crystal somewhat elongated on [100]. It is alike above and below and shows no evidence of twinning. Crystal of poor quality.
- FIG. 12. Tsumeb, S. W. Africa (No. 93927). Plan of a stout prismatic crystal elongated on [001]. Regarded as a twin. No re-entrants since terminal faces are normal to twin plane.
- FIG. 13. Chile (Micromount). Projection of a crystal, thin tabular and elongated on [010]. It is untwinned and was confirmed as brochantite by optical tests.
- FIG. 14. Collahurasi, Chile (Micromount). Plan of a crystal, thick tabular and elongated on [010]. Drawn as a twin but shows no re-entrant, as the form α is normal to the twin plane.
- FIG. 15. Cornwall (Micromount). Plan of a tablet, thin parallel to {100} and elongated on [010]. Interpreted as a twin because no negative form corresponding to {104} was found on untwinned crystals.
- FIG. 16. Tintic, Utah. Reproduction of Figure 2 in Dana, *System*, page 926. See section on uncertain forms.
- FIG. 17. Frisco, Utah (Micromount). Plan of a twin crystal, elongated on [001]. The simplest combination found.
- FIG. 18. Eureka Hill, Tintic, Utah (No. 92374). Plan of a crystal like Figure 11, untwinned and elongated on [100]. Terminated in the back by a cleavage plane.
- FIG. 19. Same locality as last (No. 92390). Plan of a crystal without re-entrants. Crystal of poor quality.
- FIG. 20. Vaskö, Banat, Hungary. Plan of a crystal fragment, untwinned.

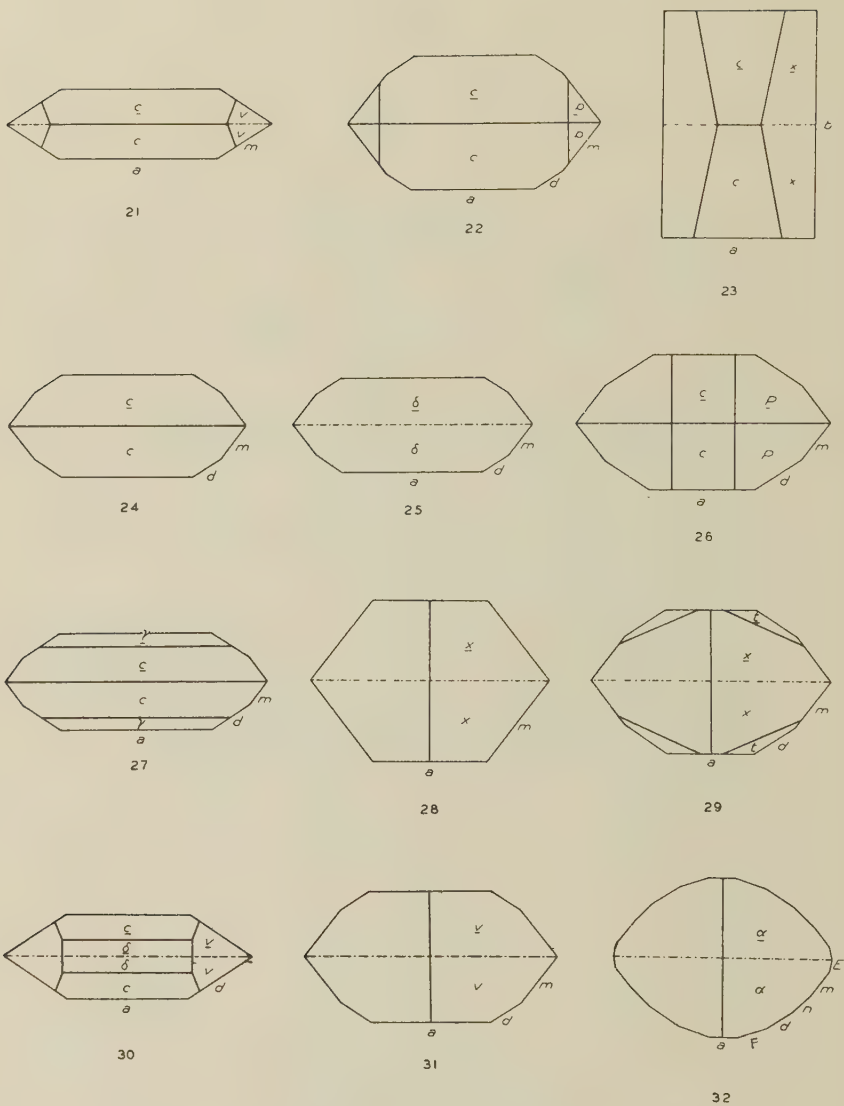


PLATE III. BROCHANTITE

Monoclinic interpretations of published figures of other authors. The figures are drawn in plan and are in part schematic. References are to the numbered figures in Goldschmidt's *Atlas*, Vol. I.

- FIG. 21. A twin. Siberia, Gdt. Fig. 4 and perhaps Roughten Gill, Fig. 12. Both these figures are drawn in our position.
- FIG. 22. A twin. Rezbanya, Hungary, Gdt. Figs. 7, 21, 22, and 23. We regard the slight re-entrants shown on the face *e* in some of Schrauf's drawings, and regarded by him as evidence of twinning, as oscillatory striation, common on this face of brochantite.
- FIG. 23. A twin elongated on [100]. Siberia. Variety "königine." Gdt. Figs. 31 and 34. Gdt. Figs 3 and 30 are the same combination in another position. Gdt. Figs. 2 and 6 are the same but without the basal plane.
- FIG. 24. A twin. The commonest habit of brochantite. Gdt. Figs. 5, 8 (which lacks {100}), 9, 10 and 18. In Fig. 40 *m* is replaced by a vicinal *ρ*. This habit is shown in both Dana and Hintze.
- FIG. 25. A twin. Siberia. Variety "Warringtonite." Gdt. Fig. 29. We regard the re-entrants shown by Schrauf on the faces of *m* as due to subparallel growth and not to twinning.
- FIG. 26. A twin. Rezbanya. Gdt. Figs. 13, 14, 17 and 20.
- FIG. 27. Vaskő, Hungary. Gdt. Fig. 44. The same figure is given by Eakle (1908) for Cerro Gordo, Calif. Eakle figures as a simple crystal what we interpret as a twin but states that the crystals have commonly but one face of *e*, which would indicate then an untwinned crystal.
- FIG. 28. Tintic, Utah. Gdt. Fig. 37. This is probably a twin but would show no re-entrant. Dana, Fig. 4. Figured by Lacroix (1910) from Maures, France.
- FIG. 29. Tintic, Utah, Gdt. Fig. 41. Twinning inferred, as the form *x* would show no re-entrant. The form *t* {252} known only from this figure. Elongation on [001].
- FIG. 30. New Caledonia. Gdt. Fig. 42. Interpreted as a twin without re-entrants. Elongation on [010].
- FIG. 31. Collahurasi, Chile. Gdt. Fig. 43. A twin without re-entrants. Elongation on [001]. Compare our Fig. 14, Pl. II.
- FIG. 32. Katanga, Belgian Congo. Schoep (1927), Fig. 3. A twin without re-entrants. Elongation on [001]. The only reported occurrence of the prisms *E* and *F*.

Interpretation of older drawings of brochantite. In Goldschmidt's *Atlas*, vol. I, Plates 233-235, there are forty illustrations of brochantite crystals. In our Plate III we have reproduced in plan a number of these crystals with the new position and lettering. Our interpretation is, of course, open to doubt but in most cases is highly probable. Many of the figures are shown as doubly terminated crystals, but careful reading of the original papers shows that this is rarely justified by the material studied. For example, in the many figures of Schrauf, but one, Fig. 13, was doubly terminated and that shows, as it should in the sense of our monoclinic setting, a deep re-entrant due to twinning. Figures 28, 32 and 33 have not been reproduced in our series; the interpretation is not clear unless it is assumed that the form k be taken as the equivalent of our $\{\bar{1}62\}$. Since this form is normal to the twinning plane, it forms no re-entrant; but it is usually rounded and difficult to measure accurately. In that case, these figures are somewhat like our Fig. 14 but with different modifying planes. The explanations accompanying Plate III indicate our analysis of many of the figures.

Reference has already been made to the peculiar difficulty of proving the presence of twinning by the optical method and the reason for it. The new setting requires a revised statement of the optical orientation which is now as follows, with the data of Larsen's tables:—

Biaxial negative. $2V = 77^\circ \pm 2^\circ$. $r < v$ medium.

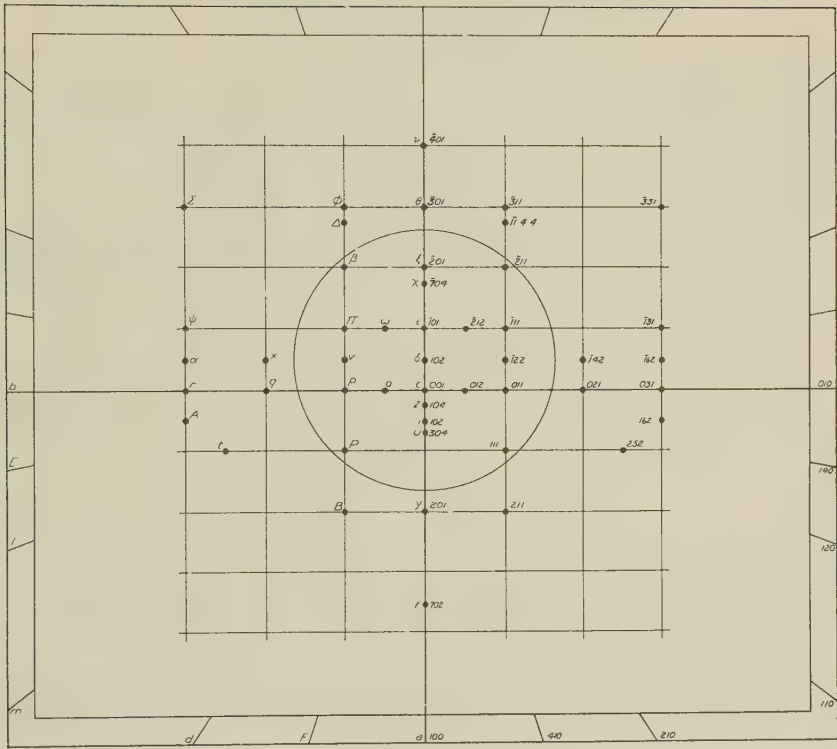
Slightly pleochroic in bluish greens.

$X = a$ very nearly = 1.728

$Y = b$ = 1.771

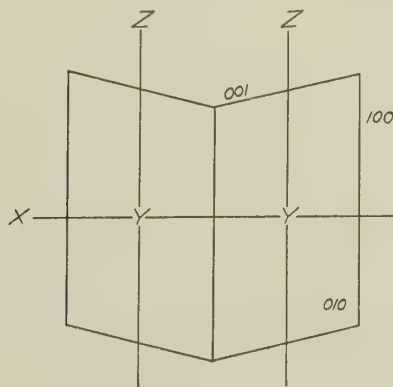
$Z = c$ very nearly = 1.800

Figure 34 is intended to show this orientation in the case of a twin crystal.



33

FIG. 33. Gnomonic projection of the forms of brochantite.



34

FIG. 34. Optical orientation of twin crystal of brochantite.

X-RAY STUDY OF BROCHANTITE

By W. E. RICHMOND

The x-ray study was made on a transparent crystal approximately equidimensional, about 0.5 mm. in diameter. It was free from twinning except for a minute lamella, which could just be seen as a line on the basal plane parallel to $\{100\}$.

Rotation and Weissenberg zero and first layer-line photographs were taken rotating about $[010]$. A Weissenberg zero layer-line photograph was also taken about $[001]$. The calculation of these photographs yielded the following values:—

$$a_0 = 13.05$$

$$b_0 = 9.83$$

$$c_0 = 5.85$$

$$V_0 = 750 \text{ cubic } \text{\AA}$$

$$a_0 : b_0 : c_0 = 1.328 : 1 : 0.611^5, \beta = 103^\circ 22'$$

$$a : b : c = 1.3283 : 1 : 0.6135, \beta = 103^\circ 21' \text{ (morphology)}$$

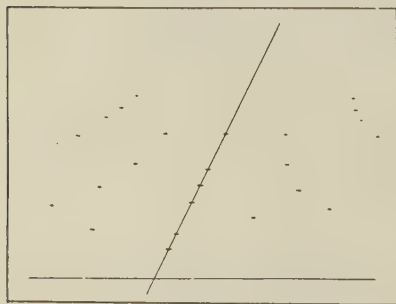
The space group is $C_2^5 - P 2/a$ determined from the following reflections:

(hkl) with all orders present

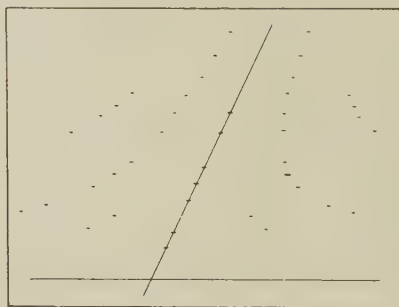
$(h0l)$ with h even

$(0k0)$ with k even

Symmetry. The first layer-line Weissenberg photographs about $[010]$ confirm the monoclinic symmetry, as may be seen in Fig. 35, which is a tracing of the photograph of the first layer line. The absence of symmetry in the arrangement and intensities of the spots here, in contrast to the symmetry shown in Fig. 36, traced from a similar photograph of a twin crystal, leave no doubt that the crystal is monoclinic.



35



36

FIG. 35. Tracing of a Weissenberg x-ray photograph of the first layer-line about $[010]$ of an untwinned crystal of brochantite.

FIG. 36. Tracing of a Weissenberg x-ray photograph of the first layer-line about $[010]$ of a twinned brochantite crystal.

Content of the unit cell. An analysis by Ford (1910) and a new specific gravity determination (3.97^*) was used for computing the content of the

* On a single crystal, by the *torsion microbalance*.

unit cell, the results of which are given in the following table:

	1	2	3		4	5	6
CuO	70.29	70.43	0.885	Cu	0.885	15.98	16
SO ₃	17.54	17.58	0.220	S	0.220	3.98	4
H ₂ O	11.96	11.99	0.667	H	1.334	24.10	24
				O	2.212	39.95	40
	99.79	100.00					

1. Average of two analyses; analyst, W. E. Ford.
2. Analysis calculated to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Number of atoms in the unit cell.
6. Theoretical number of atoms in the unit cell.

This gives the formula $\text{Cu}_4(\text{SO}_4)(\text{OH})_6$, and the unit cell contains four such molecules.

ACKNOWLEDGMENTS

The author is unwilling to bring this paper to a close without expressing his indebtedness to those who have aided him in its preparation. Dr. Foshag not only loaned me his measured crystals for study but permitted me to publish the facts of the monoclinic character of brochantite, which he had established. Dr. Tunell confirmed our *x*-ray analysis of the symmetry of brochantite. Dr. Berman studied the optics and specific gravity. Miss Dowse and Mr. Switzer prepared the illustrations after the author's sketches.

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IMPROVED TECHNIQUE IN MICROPYCNOMETRIC DENSITY DETERMINATION

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Geophysical Laboratory, Carnegie Institution of Washington.

The uncertainties in measuring the volume of a liquid in a pycnometer¹ are largely overcome if the pycnometer is filled just full, as determined by reflecting light from the meniscus of the filling liquid when the meniscus is flat across the top of the pycnometer. For a large pycnometer other factors than volume may be of major importance, but for a micropycnometer, reproducibility of volume, and accuracy of weighing are the chief considerations.

A micropycnometer of this type may be made from a thick-walled capillary tube, for which the length and bore can be made to suit the material of the test sample. The one here used was about 5 cm. long, 4 mm. wide, and 1.6 mm. bore, with a volume of 0.1110₇ cm.³. The inside of the closed end was thoroughly rounded but not bulged. The open end was ground flat and polished. To prevent chipping, the end of the capillary was filled with plaster of Paris and a fine abrasive used from the start. A plaster cast around the end of the capillary aided in obtaining a smooth flat surface, although extreme flatness was not required. The pycnometer was cleaned so as to avoid at the top any extraneous surface effects. It was then almost filled with water, and was suspended vertically on the balance.

A long, narrow source of light, such as a slit in a screen in front of a diffuse light, which would be equivalent to a width of an inch or less at about 20 feet, was arranged horizontally to reflect from the top of the pycnometer at a glancing angle of about 10°. If the slit could have been behind the balance the adjustment would have been easy, but the slit was between the balance and an overhead light, and had to be reflected by an adjustable mirror just behind the pycnometer in the balance case. The slit illuminated the top of the pycnometer evenly, and the liquid was evenly illuminated when it just filled the pycnometer, but when the meniscus was significantly curved the reflection of the slit in it was narrowed.

The reflections should be watched through the glass door of the balance case while weighings are being made. A little magnification and a fixed point of observation are desirable. A reading telescope (or microscope) with a working distance of 6 to 10 inches is best, but a reading glass fixed, and covered except for a small aperture, may be used.

¹ (a) Bannister, F. A., and Hey, M. H., *Min. Mag.*, 25, 30-34 (1938); (b) Winchell, H., *Am. Mineral.*, 23, 805 (1938).

Temperatures in the balance case should be known within a few tenths of a degree.

A droplet of water was added to make the meniscus slightly convex, and the meniscus was observed as the water evaporated. The top of the pycnometer now looked bright, and a bright, narrow, curved line crossed the meniscus. This line slowly straightened, then it rapidly widened till it covered the whole meniscus, and then quickly narrowed. The pycnometer was full at the instant the surfaces of both meniscus and pycnometer were completely illuminated. Observations were repeated with weights adjusted and the balance swinging so that evaporation was accompanied by a shift of the zero, and finally, while the change from convexity to concavity was in progress a record was made of the swings with respect to the time at which flatness occurred.

The capacity of this pycnometer was so small that only rough temperature control was required. Water changes volume one part in a thousand in the intervals 4—16—25—29°.

The sensitiveness and speed of the balance, and the rate of evaporation of the liquid are factors in the accuracy. The humidity of the balance case can be controlled somewhat. After calibration with the water the density of other liquids may be found, but if some other wetting liquid is required its density may first be found by some other method.

Careful cleaning (as with nitric and chromic acids), drying in a vacuum, and weighing of the pycnometer between fillings are essential.

The micropycnometer is most useful for small amounts of liquid, and small volumes of heavy substances. However, to test the accuracy of fillings and weighings, standard quartz was used here. The percentage accuracy of density determinations is about the same for equal volumes of material of different densities. Because the fullness can be determined with methylene iodide as accurately as weighings can be made on an ordinary analytical balance (in this case to about 0.00003 g.) the accuracy in this type of pycnometer is about in proportion to the density of the liquid used in the calibration and immersion. The following changes in the formula and explanation below apply when other liquids than water are used: for specific gravity, "relative density"; and for water, "liquid."

$$\text{Sp. gr.} = \frac{\text{Weight of the sample}}{(\text{wt. of sample} + \text{wt. of pyc. full of water}) - \text{wt. of pyc. filled with sample and water}}$$

This is reduced to density, g./cm.³, by multiplying by the weight of 1 cm.³ of water at the temperature of observation. At 16° = 0.999₀, at 21° = 0.998₀, at 25° = 0.997₁, at 29° = 0.996₀.

Density, g./cm.,³ was determined on small quantities of clear quartz: on 0.0325₈ g. = 2.649₈; on 0.0223₀ g. = 2.649₁. For a milky quartz the value was 2.633.

The only weights not compensated here are of (1) the crystals (numerator) and (2) water displaced (denominator).

The volume found with single weighings of water for a pycnometer of 0.6 mm. bore was 0.0332₆ at 26.5°, and 0.0332₀ at 27.7°. The calculated difference is 0.00001. The determination of the moment at which the pycnometer was full was decidedly more accurate than the weighings. There appears to be no advantage in using a small-bore pycnometer, which is difficult to fill, unless a microbalance is used with it.

The change of density over this range per 1° C. for toluene² is 0.0009; methylene iodide,³ 0.0027; 1,1,2,2-tetrabromoethane,⁴ 0.0022; for bromoform,^{1a} 0.0021.

Slowly volatile liquids can be brought to the level of the surface of the pycnometer by a change of temperature or by transferring liquid by means of a small bristle. Liquids that creep are not suitable for accurate density determination by this method, but the capillary may be almost filled and the temperature raised, or a droplet added by means of a bristle.

The following technique in filling a pycnometer in both micro- and macro-pycnometric methods has been found quite simple and practical. The pycnometer containing the sample⁵ is suspended in a desiccator and first evacuated. The desiccator is provided with a separatory funnel containing the displacement liquid. The end of the funnel is a finely drawn capillary and projects into the pycnometer a short distance above the sample.

By means of the stopcock in the funnel, the vacuum in the desiccator is gradually lowered to that of the vapor pressure of the liquid. This enables particles freed from adsorbed air to be first thoroughly wetted by the liquid. By careful manipulation in lowering the pressure in the desiccator, enough liquid is admitted to cover the sample entirely.

In other cases this technique, which assures reproducibility, can be used to eliminate the various errors in the measurement of a liquid in a capillary.

² Computed from unpublished measurements by John S. Burlew.

³ Timmermans, J., et Mme. Hennaut-Roland, *Jour. chim. phys.*, **29**, 529 (1932).

⁴ Walden, P., and Swinne, R., *Zeits. phys. Chem.*, **82**, 281 (1913).

⁵ Whenever possible each individual grain of the sample should be first positively identified as such by at least one of its physical characteristics. Handling the individual particles or minute crystals with tweezers with fine points of celluloid, or a medicine dropper with an extremely fine and flexible drawn end, moistened with the displacement liquid, was found very convenient.

CRISTOBALITE IN SOUTHWESTERN YELLOWSTONE PARK

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INTRODUCTION

Megascopic cristobalite has been found at several localities in the United States. Rogers¹ has described specimens from three California localities and in his 1922 paper reports that he has obtained specimens from five others. Shannon² found cristobalite crystals 0.5 mm. in size in vesicular cavities in basalt at Spokane, Washington. Foshag³ has described megascopic cristobalite from Obsidian Cliff in Yellowstone Park, and Larsen⁴ has reported cristobalite of visible size in southwestern Colorado. In spite of these occurrences, megascopic cristobalite is rare although no longer an oddity. Microscopic cristobalite, on the other hand, is much more widespread. Larsen (*op. cit.*, 682) reports that it is fairly widespread in about one-tenth of the lavas of the San Juan region, but adds that it rarely makes up more than a small fraction of one per cent of any lava.

The purpose of the present paper is to call attention to additional occurrences of cristobalite in Yellowstone Park and to record certain observations bearing on the genesis of the mineral. The cristobalite is not only widespread but relatively abundant.

OCCURRENCES

The writer's attention was first called to the new occurrences of cristobalite by Dr. Francois Corin of the Belgium Geological Survey who reported tiny white pellets in the obsidian along the road about a half mile south of the junction of the Firehole and Gibbon Rivers (Fig. 1). Recently the writer was afforded opportunity to check the identity of the mineral and to determine its relative abundance in this immediate region.

¹ Rogers, A. F., The occurrence of cristobalite in California: *Am. Jour. Sci.*, (4), **XLV**, 222-226 (1918).

Rogers, A. F., A new occurrence of cristobalite in California: *Jour. Geol.*, **30**, 211-216 (1922).

² Shannon, Earl V., On siderite and associated minerals from the Columbia River basalt at Spokane, Washington: *Proc. U. S. Nat. Mus.*, **62**, Art. 12, 1-17, with pls. 1-3 (1923).

³ Foshag, W. F., The minerals of Obsidian Cliff, Yellowstone National Park, and their origin: *Proc. U. S. Nat. Mus.*, **68**, Art. 17, 1-18, with pls. 1-4 (1926).

⁴ Larsen, E. S., and others, Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colorado: *Am. Mineral.*, **21**, 679-701, Section 2, The silica minerals, 681-694 (1936).

The cristobalite pellets at the locality examined by Dr. Corin average less than 0.2 mm. in size. Since their discovery, the writer has found other exposures in which the pellets average slightly less than a millimeter in diameter with some slightly larger. Most of the megascopic cristobalite pellets described from other American localities are also less than a millimeter in diameter. A recent text⁵ mentions cristobalite "eggs"

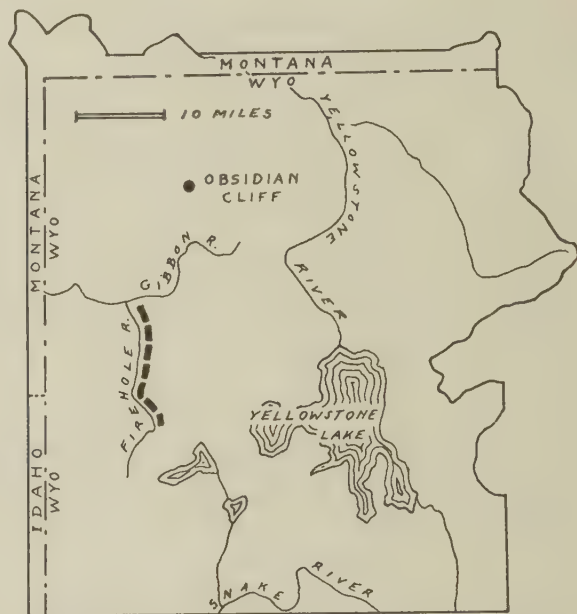


FIG. 1. Yellowstone National Park. Cristobalite has been described from Obsidian Cliff. The new localities are indicated by the heavy broken line.

two inches in diameter from near Little Lake, California. In the specimens from this locality in the collection at Columbia University, the cristobalite occurs in lithophysae up to two inches in diameter but the pellets themselves are only about a millimeter in size.

The cristobalite herein described occurs in the rhyolite lava exposed along the road for 14 miles south of the junction of the Firehole and Gibbon Rivers. Some of the exposures contain visible cristobalite in appreciable quantity; others have so little that careful and intensive search is required to find it; and a few show none at all. No attempt was made to trace the cristobalite-bearing rock away from the road.

⁵ Quartz Family Minerals, Dake, H. C., Fleener, F. L., and Wilson, B. H., McGraw-Hill Book Co., New York, 1938, p. 85.

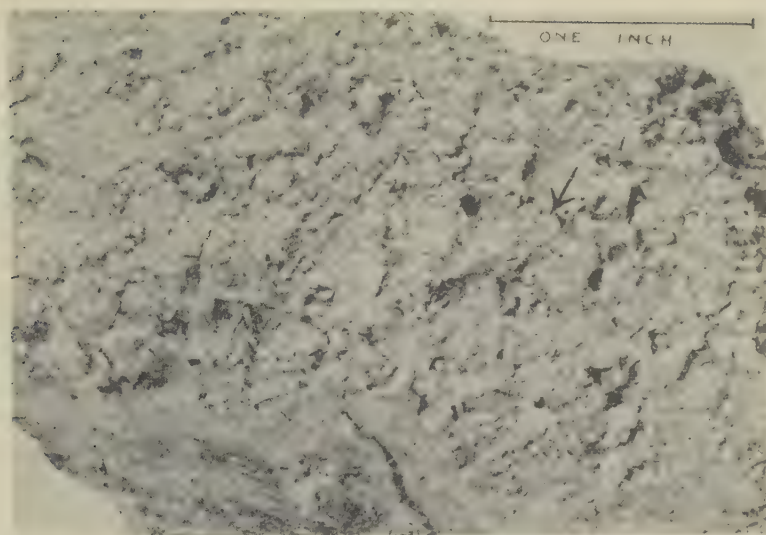


FIG. 2. Specimen showing megascopic cristobalite. Arrow indicates a cluster of the pellets. From 0.6 mile south of junction of Firehole and Gibbon Rivers. (Photograph by James Bush.)

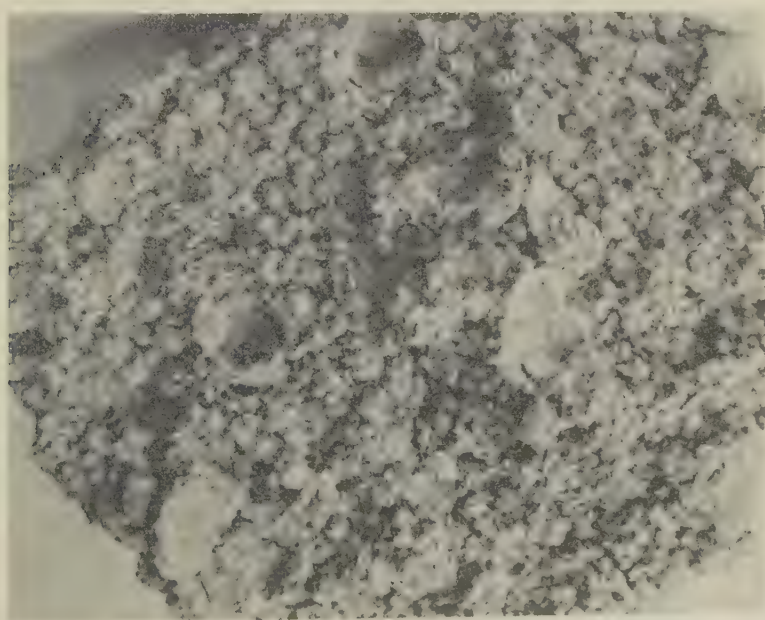


FIG. 3. Specimen showing an agglomeration of spherulites and lithophysae with almost no intervening glass. Cristobalite pellets are discernible in some of the lithophysae. (Photograph by James Bush.)

Many of the outcrops are of a perlitic, flow-banded vitrophyre. In many exposures the rock is strongly folded and brecciated. The cause of the folding and brecciation was not investigated, but it is interesting to note that the cristobalite is largely confined to the disturbed rocks. The vitrophyre contains numerous spherulites and lithophysae. The latter bodies, though generally of small size, often exceed an inch in diameter. The glass itself is often mottled due to differential alteration. In some specimens only the kernels of the perlitic granules are black; the intervening glass is gray. The mottled varieties are the most porous and inasmuch as the cristobalite content varies with the porosity, the black, fresher-appearing glass shows little or no cristobalite, while the mottled varieties contain much. The porosity is due to the presence of lithophysae and of highly irregular, sometimes long drawn out cavities which often ramify and branch through the rock in so thick a network that the rock appears almost sponge-like. Many of the long irregular cavities clearly represent strings of lithophysae joined by destruction of their communal walls. Lithophysae in different flow bands are often connected across the grain of the flowage. However, many irregular cavities bear no resemblance to individual or compound lithophysae. These will be discussed later.

The cristobalite occurs as tiny spheres on the walls of lithophysae and other cavities (Figs. 2 and 3). The pellets are milky white and vary from translucent to opaque. Some are covered by tiny, tabular prisms of tridymite. In the exposures 2.6 miles south of Madison junction many of the lithophysae are more than an inch in diameter and the largest cristobalite pellets, about a millimeter in diameter, are to be found here. Some of the specimens collected show only an agglomeration of spherulites and lithophysae; there is almost no intervening glass. Except for the lithophysae, then, the pore spaces in these specimens are highly irregular.

The remaining exposures show stony rhyolite with very little pore space; the rock is massive, with neither layering nor brecciation, and, in common with the undisturbed facies of the glassy rock, contains little cristobalite. Where the stony rhyolite is altered by hydrothermal activity, cristobalite is frequently found in the more affected portions. In some exposures hydrothermal alteration has been localized along joint planes and cristobalite is found only along these planes.

IDENTIFICATION OF MINERALS

The cristobalite and associated minerals were first examined in thin section (Fig. 4). The cristobalite occurs in subround pellets, individually or in groups. Its refractive indices with respect to balsam, its birefrin-

gence, and its peculiar fracture check with the descriptions in standard works of reference. The cristobalite is associated with tabular prisms of tridymite, and with encrustations of chalcedony.

The identity of the silica minerals was then checked by immersion in index liquids. The indices of the cristobalite lie between 1.481 and 1.489; those of the tridymite lie below 1.481. These observations agree with published data.

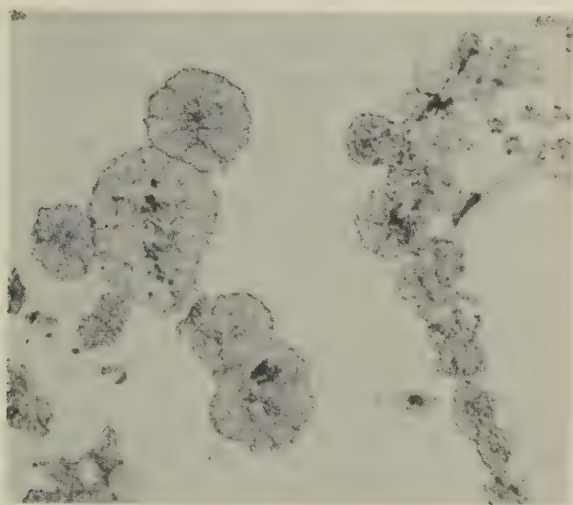


FIG. 4. Cristobalite pellets in rhyolitic vitrophyre. Note characteristic wavy fracture. The largest pellet is about a millimeter in diameter. (Photograph by E. N. Cameron.)

A quantity of the cristobalite was then separated from crushed material for *x*-ray examination.⁶ The *x*-ray pattern indicates a mixture of cristobalite and chalcedony.

ORIGIN OF THE CRISTOBALITE

Foshag (*op. cit.*, 13-17), in his paper on the cristobalite of Obsidian Cliff, attributes the formation of the cristobalite at that locality to a reaction between aqueous solutions trapped within the lithophysae and the glassy wall rock, rather than to introduction of material by invading solutions. As evidence against introduction of the silica minerals by aqueous solution, he points out that the glass is fresh to the very walls

⁶ The separation was made under a binocular-microscope by means of an appliance described by the writer some years ago. (A simple appliance for the manipulation of individual detrital grains of minute size, *Sed. Petrol.*, 2, 160-161 (1932).) Its ease of manipulation recommends the instrument for use in the handling of tiny mineral or rock particles.

of the lithophysae in spite of its susceptibility to alteration by hot aqueous solutions. The freshness of the glass is all the more remarkable in Foshag's opinion because of the great volume of solvent that would be required to introduce the relatively insoluble cristobalite and associated minerals. He believes introduction by gaseous solutions is also improbable because of the lack of evidence of abundant supplies of fluorine, chlorine, and other mineralizers necessary to transport the molecules of the minerals of the lithophysae in the form of volatile compounds. Analyses published by Foshag show a marked similarity in composition among the lithophysae, spherulites, and the obsidian. This supports his hypothesis that the minerals of the lithophysae of Obsidian Cliff were formed from materials which originated within the lithophysae themselves by reaction between trapped aqueous solutions and the glass.

In the writer's opinion much of the cristobalite of the lithophysae in southwestern Yellowstone may have formed in a similar fashion. The presence of the greatest volume and the largest pellets of cristobalite in the largest lithophysae may be evidence of such an origin. There are reasons for believing, however, that some of the cristobalite outside the lithophysae was formed by invading solutions. The local, intense hydrothermal alteration of the rocks suggests penetration by solutions. In many of the specimens the glass is so altered that only the innermost kernels of the perlitic granules retain their original black color; the intervening glass is gray. In other specimens, to be described shortly, the glass has been entirely removed.

The most suggestive line of evidence favoring invading solutions is that in some exposures of relatively fresh rock, cristobalite was found only along joint cracks where the rock was appreciably altered, as though the fractures acted as passages for siliceous solutions. In other specimens occasional tiny seams of cristobalite are found, but since these lie parallel to the flowage, the possibility remains that they were formed by reaction between the glass and solutions which dissolved their way along certain flow planes from nearby lithophysae. Many of the long drawn out cavities may represent a similar type of solution along flow planes by solutions originally trapped in lithophysae. Others, however, may well have been formed by invading fluids following flow layers.

One of the specimens (Fig. 3) shows a surface on which practically no glass is visible. It displays a mixture of spherulites and lithophysae separated by irregular spaces. That these spaces were originally occupied by glass may be inferred from the presence of remnants of intervening glass. In view of their intimate association it seems reasonable to suppose that the alteration of the rock and the removal of the glass

was accomplished by the same agencies. The rhyolite over wide areas in Yellowstone is being altered at the present time by rising aqueous and gaseous solutions. In the exposures examined, cristobalite is most common where the rock is altered. Hence it is probable that the leaching of the glass and the precipitation of at least part of the cristobalite was accomplished by invading solutions. It is quite possible that cristobalite is being formed at the present time.

The high porosity and the large percentage of cristobalite in some of the specimens might also be considered evidence of invading solutions. It is difficult to imagine so great a concentration of aqueous solution during the solidification of the rhyolite as to fill all the pore spaces in these highly porous specimens, and to furnish all the silica of the contained cristobalite. It is simpler to suppose that much of the porosity is due to the solvent action of invading solutions, and that part at least of the cristobalite was formed by interaction between invading solutions and the glass. Although much of the silica was undoubtedly liberated from the glass by the invading solutions, some of it may have been introduced by these solutions.

SUMMARY

New occurrences of cristobalite are described from southwestern Yellowstone Park. Some of the cristobalite was probably formed by reaction between solutions trapped in lithophysae and the cavity wall rock, as proposed by Foshag for the cristobalite of Obsidian Cliff. The remainder may have been formed by reaction between invading solutions and the glass. Inasmuch as aqueous and gaseous solutions are permeating the rocks over wide areas in Yellowstone Park at the present time, cristobalite may even now be in process of formation.

ACKNOWLEDGEMENTS

The writer is indebted to Dr. W. F. Foshag for critical examination of the manuscript and to Drs. E. N. Cameron and Arthur Hagner for helpful suggestions. Professor P. F. Kerr graciously permitted use of the x-ray facilities at Columbia University.

QUANTITATIVE MEASUREMENT OF DICHROISM IN TOURMALINE

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INTRODUCTION

With the Glan¹ spectrophotometer a quantitative comparison of the absorption spectra of one vibration direction of a crystal plate may be made with an unabsorbed spectra from the same source of light. By repeating the observations, after rotating the crystal to the other extinction position, the other vibration direction may be compared with the same source. The ratio of the two intensities for any given wavelength may then be calculated. Two separate slits are used and the intensity of the light through these two slits is equalized before inserting the crystal plate in front of one of the slits. If the light source fluctuates during the course of the observations so as to change the relative illumination of the two slits, the results are in error. Because minerals are apt to show variation in color distribution or because they may contain irregularly distributed inclusions, another source of error is introduced since the slit necessarily covers two different portions of the crystal plate during the course of the experiment.

The Koenigsberger² microphotometer eliminates the first of these two errors because it uses a double image prism of calcite to produce identical images of a single circular aperture. A circular aperture is used instead of a slit to reduce the second type of error because by careful adjustment the same portion of the crystal plate may be used in measuring the absorption in both extinction positions. The microphotometer reduces the error due to unequal color distribution by confining the observations to a very small clear area.

The measurement of dichroism involves a determination of the nature of the difference in color, or the difference in absorption throughout the visible spectrum, between the ϵ and the ω rays. Hence both of the methods mentioned above are indirect methods of measuring dichroism because each vibration is compared to a standard spectrum and the ratio of the intensities calculated through this outside standard. The method described in this paper is a direct method of comparing two

¹ Glan, P., Ueber ein neues Photometer: *Wiedem Ann.*, Band 1, 351-360 (1877).

² Koenigsberger, J., Ueber ein Mikrophotometer zur Messung der Absorption des Lichts: *Zeits. Instrum.*, Band 21, 129-133 (1901). Also, Ueber die Absorption des Lichtes in festen Körpern: *Habilitationsschrift*, Teubner, B. G., 1900, 48 pp. Abst.: *Zeits. Krist.*, 36, 620-623 (1902).

images which are identical except for the direction of polarization and for the difference in intensity, due to unequal absorption. The double refraction of the crystal under observation is used to separate the two images which are formed by light rays which have passed through the same part of the crystal. It is free from errors due to fluctuations in the intensity or spectral characteristics of the light source or in the distribution of light over the entrance slit. The apparatus consists of a monochromator and a one-circle goniometer or spectroscope with a cap-nicol mounted on the eyepiece of the goniometer or spectroscope. The errors in the method are mainly dependent upon the personal equation of the observer when matching visually the intensities of light in the two images.

DESCRIPTION OF METHOD

A prism with the refracting edge perpendicular to the c -axis was ground and polished from a transparent and nearly flawless crystal of light green tourmaline from near Swakopmund, South West Africa.

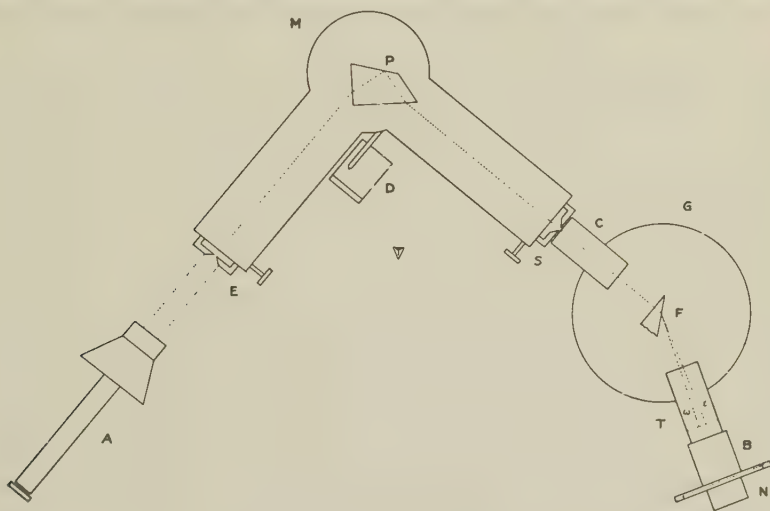


FIG. 1. Arrangement of apparatus for measurement of dichroism. *A*, arc-light; *M*, monochromator; *E*, entrance slit; *P*, constant-deviation prism; *D*, wave-length drum; *S*, exit slit; *C*, collimator; *G*, goniometer; *F*, dichroic mineral prism; *T*, telescope; *B*, collar; *N*, cap-nicol.

One surface of the wedge was crystallographically a prism face of the crystal which was slightly ground and polished to remove minor surface imperfections. This face was blocked off by opaque paper except for a narrow slit parallel to the refracting edge through which the light rays entered the crystal. The prism angle of this wedge was ground to about 32° , a convenient angle which would separate the ordinary and extra-

ordinary rays to such an extent that the separate images of the entrance slit formed by these rays would appear side by side in the telescope of the goniometer, but would be separated by only a narrow interval.

The prism was mounted upon a one-circle goniometer with the refracting edge vertical. The Websky signal slit on the front of the collimating tube was removed and a Fuess-Wülfing monochromator mounted in front of the collimating tube so that the exit slit of the monochromator could serve as the entrance slit of the collimator (Fig. 1). The telescope was then focused upon the exit slit of the monochromator which served as a signal. The prism was adjusted as in the determination of the indices of refraction by the method of perpendicular incidence with the natural prism face of the crystal perpendicular to the beam of light emerging from the collimator. That portion of the beam which fell upon the small slit made in the opaque paper covering the prism face of the crystal was transmitted through the crystal normal to the prism face and upon emerging from the crystal separated into two beams, one vibrating in a vertical plane, and the other vibrating horizontally. When seen through the telescope these two beams formed images of the exit slit of the monochromator which appeared side by side in the field of the telescope and were polarized at right angles to each other. A simply constructed collar of brass was designed to fit around the telescope of the goniometer. This accessory was rigidly attached to the telescope, but contained a bed perpendicular to the telescope axis which allowed the rotation of a cap-nicol of the same design as used with the polarizing microscope. The nicol carried a graduated circle, while the flange of the brass collar bore but a single mark.

When the vibration direction of the cap-nicol was parallel to the vibration direction of the image formed by the ordinary ray, that image was transmitted by the cap-nicol, but the image formed by the extraordinary ray was completely extinguished. On rotating the cap-nicol the ordinary image decreased in intensity while the extraordinary image increased in intensity. These two images, upon continued rotation of the nicol, finally became equal in intensity and from the angle of rotation of the cap-nicol a ratio expressing the relative intensities of the two transmitted rays was calculated.

If we let AE represent the amplitude of the vibration of the extraordinary ray for any given wave length, AO equal the amplitude of the ordinary ray, and AP , the vibration direction of the nicol at the position of equal illumination, then from Fig. 2:

$$AP = AO \cos \alpha$$

$$AP = AE \sin \alpha, \text{ or}$$

$$AO \cos \alpha = AE \sin \alpha$$

in which α is the angle of rotation of the cap-nicol from the position of complete transmission of the ordinary ray and extinction of the extraordinary ray. Then,

$$AO = \frac{\sin \alpha}{\cos \alpha} = \tan \alpha.$$

It must be remembered that this value represents the amplitude of the ordinary ray when the extraordinary ray is unity and, since the intensity is proportional to the square of the amplitude, the visual intensity of the ordinary ray would be equal to $\tan^2 \alpha$. Changing to a percentage basis, $100 \tan^2 \alpha$ is the per cent transmission of the ω ray when that of the ϵ ray is 100%.

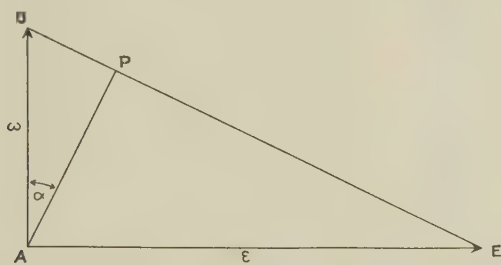


FIG. 2. Diagrammatic derivation of formula for transmission of ω -ray compared to ϵ -ray.

The relative intensity of the ordinary ray with respect to the extraordinary ray of the tourmaline was compared for twenty different wave lengths of the spectrum. The accuracy of the determination of the position of equal brightness of the two images involves considerable in the way of a personal factor. Different individuals have different degrees of acuity of perception of relative brightness. The ability of the observer to repeat his readings of the angle of rotation increases rapidly with experience and training, and drops off sharply with fatigue or eye strain. The absolute intensity of the image is also an important factor in matching intensities. The greatest difficulty is experienced when the images are too bright, so it is desirable to regulate the intensity of the light source so that the images are moderately weak in absolute brightness. In order to minimize the personal equation a series of twenty readings were taken at each wave length. The position of equal illumination was determined by alternately approaching this position by rotating the nicol clockwise and then counterclockwise toward the position of equal illumination.

From these successive readings the average visual intensity of the

ω ray was calculated, together with the average deviation of the mean for the readings at each wave length. These values are given in Table 1. The values given in the second column represent on a percentage basis the visual intensity of the ω ray compared to that of the ϵ ray when the intensity of the ϵ ray is taken as unity. The third column gives the average deviations. In Fig. 3 these values are shown diagrammatically.

TABLE 1.

Wave-length $\mu\mu$	Per cent Transmission ω ray	A.D.	Wave-length $\mu\mu$	Per cent Transmission ω ray	A.D.
427.5	2.71	.04	538	10.24	.10
445	3.60	.05	545	10.77	.09
465	5.20	.05	567	12.01	.10
480	6.77	.07	585	11.59	.10
489	7.85	.06	600	9.66	.08
495	8.76	.10	615	7.88	.07
502	9.76	.09	630	6.45	.09
510	10.02	.06	650	5.24	.06
520	9.60	.08	670	4.45	.07
530	9.64	.08	685	3.99	.06

The curve thus plotted shows a slight change in trend between 500 and $550\mu\mu$, and it is important to determine whether this is due to experimental error, or is a characteristic of the material studied. The percentage deviation in this region averages .88%, but for a margin of safety this might wisely be increased to 1.50%. Using this latter figure, there appear on Fig. 3 two additional curves in the region of 500 to $550\mu\mu$ representing the probable limits of error in both directions. This indicates that the change in trend is beyond the limits of experimental error.

The light was transmitted through a small portion of the wedge of the tourmaline crystal. The average thickness of this small area of the wedge, $1.35 \text{ mm.} \pm .01 \text{ mm.}$, was determined by measuring the distance of the center of the small slit made in the opaque paper from the refracting edge of the crystal and multiplying that value by the tangent of the refracting angle. Because the image in the telescope is produced by all rays transmitted through the crystal, its intensity is proportional to the average thickness of that portion of the crystal through which the light passes.

The curve does not represent a comparison between the spectrum of

the ω ray and the spectrum of white light, but a quantitative visual comparison of the spectrum of the ω ray with that of the ϵ ray when the ϵ ray is taken as unity. It may also be interpreted as a measure of the ability of this crystal to produce polarized light by absorption. At only

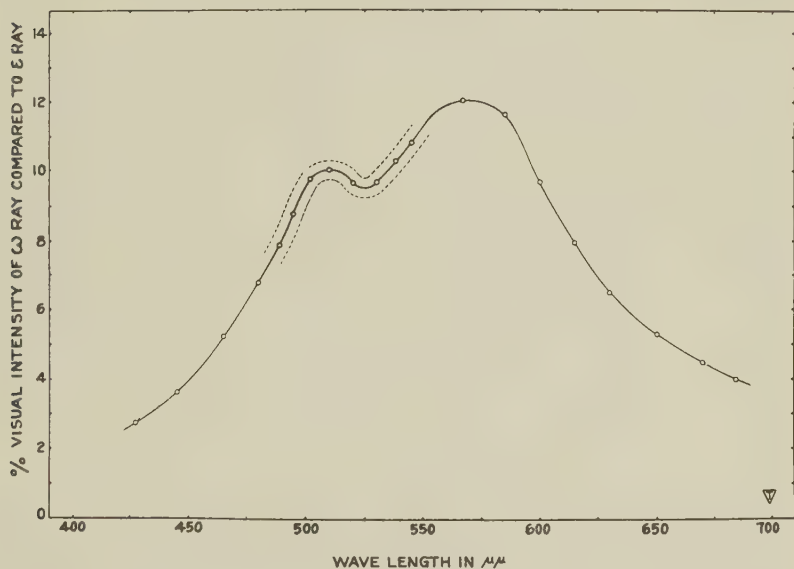


FIG. 3. Curve showing nature of dichroism in tourmaline from Swakopmund, S. W. Africa.

a few points in the middle of the spectrum does the percentage of the unabsorbed ω ray reach ten per cent of the total light transmitted. In other words, a plate of tourmaline 1.35 mm. thick cut from this crystal parallel to the c -axis would produce light by transmission which would be over 90% plane polarized.

MEASUREMENT OF DISPERSION

From the same prism used for the determination of dichroism, the indices of refraction for various wave-lengths were measured by the method of perpendicular incidence. Table 2 gives the average of two determinations, the prism having been reoriented on the goniometer for the second set of readings. The values for the indices of refraction of the ϵ ray between 440 and 656 $\mu\mu$, and for the ω ray between 478 and 632 $\mu\mu$ are probably accurate to within $\pm .0003$. As the limits of visibility are approached in either direction the precision becomes less, due to increasing weakness of the signal. The first and last figures for the indices of

refraction in each column of Table 2 are probably accurate to within $\pm .0005$. The dispersion of the ϵ ray between 440 and $671\mu\mu$ is about .0130, that of the ω ray between the same interval about .0137, and the dispersion of the double refraction about .001.

TABLE 2.

Wave-length $\mu\mu$	Indices of refraction		Wave-length $\mu\mu$	Indices of refraction	
	ϵ	ω		ϵ	ω
695	1.6205	—	486	1.6290	1.6500
671	1.6208	1.6410	478	1.6296	1.6507
656	1.6211	1.6414	470	1.6307	1.6515
632	1.6218	1.6420	460	1.6316	1.6524
610	1.6225	1.6426	450	1.6324	1.6534
589	1.6232	1.6436	440	1.6338	1.6547
570	1.6238	1.6445	434	1.6345	—
550	1.6248	1.6455	420	1.6361	—
535	1.6259	1.6463	410	1.6376	—
515	1.6270	1.6483	405	1.6382	—
500	1.6279	1.6491			

CONCLUSIONS

The method of quantitatively measuring dichroism which was used is simpler than those described in the literature and, except for the easily constructed brass collar, calls for the use of no equipment which is not commonly available in mineralogical laboratories. The simplicity of the method allows it to be used for a laboratory experiment for teaching purposes.

Absorption spectra have long been used for determining the chemical characteristics of gases and liquids. With solids the width of the absorption bands makes impossible the same degree of accuracy that can be obtained with liquids and gases. In the case of colored glasses the position of these bands is dependent upon the qualitative chemical composition of the glass, and the width upon the percentage composition of the absorbing element and upon the thickness. At some time in the future it is hoped that the dichroic character of the absorption in certain crystals may be correlated with the composition of the crystals.

NOTES ON QUARTZ "DIKES"

G. M. FURNIVAL, *Lochalsh, Ontario.*

Carl Tolman in a recent paper¹ on "Quartz Dikes" presents numerous cases from the literature of "quartz masses thought . . . to be of igneous origin." Tolman, by the phrase "quartz masses of igneous origin" refers to those masses of quartz which are believed to have formed by crystallization from an igneous melt, and uses it in contrast to "quartz veins" which have formed by deposition from highly aqueous solutions.

Physical-chemical grounds alone seem to preclude the possibility of quartz masses forming by direct crystallization from a melt. Pure silica has a melting point of 1713°C. so that existence in nature of molten silica seems highly improbable, and even were it possible its high viscosity would make injection unlikely. However, the articles quoted by Tolman and many additional articles were critically reviewed to determine the instance of such cases in the literature and the nature of the evidence upon which such conclusions are based.

The results of a study of the literature alone differ from those of Tolman and it was felt this paper would prove of interest to readers.

OCCURRENCES OF LARGE QUARTZ MASSES

J. F. Kemp in 1899 and in 1901 described a huge mass of quartz at Lantern Hill, North Stonington, Connecticut.² Kemp regards it as the "ultra acid end-member of a pegmatitic-quartz vein series." Tolman quotes Kemp and cites this as an example of a "huge quartz vein a thousand feet in width which belongs in the pegmatitic series." However, he has failed to mention an excellent description of the vein by H. E. Gregory.³ Gregory describes the vein as stockworks of quartz stringers up to fifteen hundred feet wide which has been traced several miles through aplitic granite gneiss. It consists of 98% quartz with patches of altered and partly replaced country rock. Gregory gives abundant evidence to support his conclusion that the vein has formed by a process of replacement of the gneiss by quartz deposited from hydrothermal solutions.

Tolman also cites as an example of "quartz dikes" tabular bodies of quartz near Foxdale, Isle of Man. These were probably first described by A. Harker as masses of pegmatite grading into quartz veins.⁴ G. W. Lamplugh, in a later description, regards them as having formed from thermal waters rather than from a melt.⁵ J. Lomas gives the most complete description of the veins and the alteration of their wall rocks.⁶ The evidence indicates that quartz veins deposited from hydrothermal solutions grade into pegmatitic quartz veins as the source of the material is approached.

The "White Elephant Rock" near Salem, India, was first mentioned by King and Foote⁷ and later by T. H. Holland.⁸ Here are two large masses of quartz. The descriptions, however, are brief and incomplete and the evidence too scanty to justify the conclusion that these masses have an "igneous origin," in the sense defined by Tolman.

A paper on which Tolman places considerable emphasis is one by Baumgartel⁹ in which is described an occurrence of quartz "veins" of two ages. The older, Baumgartel regards as an igneous intrusion or quartz "dike," the younger as a fissure filling deposited from hydrothermal solutions. The "veins" vary in width up to 20 cm. and are related to granite which intrudes Cambrian slates as isolated bosses. Baumgartel bases his conclusion that the older quartz bodies were intruded as igneous material on the alterations in the country rocks along them.

The Cambrian slates are metamorphosed by the granite to hornfels composed of quartz, muscovite, biotite, magnetite, tourmaline, zircon, calcite, rutile and carbonates with metacrysts of cordierite and garnet.

The quartz of the older bodies is coarse grained, clouded with liquid inclusions and has a cataclastic structure. The minerals present are apatite, spinel, magnetite, garnet, corundum, rutile, tourmaline, zircon, chalcopyrite, altered plagioclase, orthoclase and microperthite. The wall rock alteration superimposed on the contact metamorphism of the slates, and upon which the conception of the igneous origin of these bodies is based, consists of the enlargement in the grain size, alteration of the cordierite to pinite, of hornblende to calcite and chlorite, and the introduction of garnet, apatite, wolframite, scheelite and chalcopyrite. Biotite, tourmaline and zircon are increased in relative proportions.

Where quartz bodies which caused the above alteration in the metamorphosed slates pass into fresh slates they do not alter them. Baumgartel explains this by stating that the fresh slates were probably not at a sufficiently high temperature at the time of intrusion of the quartz. However, it is evident that the fresh slates represent a lower grade of metamorphism than the contact metamorphosed slates or hornfels, and, therefore, when exposed to the action of a melt (or high temperature solutions) it would seem that those rocks of lower grade metamorphism should undergo even more marked changes, and at least should be altered to the same degree as the hornfels. The evidence presented strongly suggests that the alteration described is due to other agencies than those from which the quartz bodies formed.

It seems that Tolman is not justified, on the basis of the evidence stated, in including these as "igneous quartz masses." The description suggests pegmatitic quartz veins followed by quartz veins.

That large masses of quartz have formed by the action of hydrothermal solutions is shown, in addition to the study of the large quartz vein at Lantern Hill, Connecticut, by studies of the Great Pfahl, the Bohemian Pfahl, and other large quartz veins of the Bohemian¹⁰ and Hercynian¹¹ massifs of Bohemia and Brittany, by the "Great Sulphur Vein" of Ashton Moor in the Pennines of Northern England,¹² and by the large quartz veins of Great Bear Lake.¹³

The Bohemian Pfahl has been traced a distance of fifty-five kilometers and varies in width from 30 to 100 meters. The Great Pfahl has been traced for over 150 kilometers. A third large quartz vein in the Erzgebirge has been traced 40 kilometers. Bordering the eastern margin of the Amoracin massif of Brittany, Suess describes a large quartz vein 140 kilometers long. The "Great Sulphur Vein" varies from 128 feet to 1200 feet wide and is continuously exposed for eight miles. L. M. Thompson states that the vein is composed largely of quartz but contains some chalcopyrite, pyrite, pyrrhotite and galena.

At least fifty-five large quartz veins are known to occur in the Great Bear Lake area, Northwest Territories, Canada. These occur in the region from Fort Rae to Bathurst Inlet, 350 miles north to south and 250 miles east to west, and doubtless many more than this number exist. These veins have average widths in excess of 100 feet and lengths up to 17 miles. Including stockworks some exceed a thousand feet in width. The origin of the veins has been shown to be due to alteration and replacement of highly fractured rocks along faults of major displacement by quartz deposited from hydrothermal solutions at not very elevated temperatures.¹³

QUARTZ MASSES GRADING INTO IGNEOUS ROCKS

Tolman, in addition to numerous cases of masses of quartz which grade into pegmatite dikes and which will be discussed later, cites three cases in which the quartz masses are described as grading into stocks or laccoliths of igneous rocks.

One such case which he refers to is that described by A. L. Hall¹⁴ of an "ultra-acid" or highly quartzose rock which occurs widely distributed around the margins of the Bushveldt granite in Western Secoecoeni-land, South Africa. However, in literature by A. L. Hall¹⁵ and A. L. Du Toit,¹⁶ subsequent to that quoted by Tolman, the "ultra-acid" rocks are shown to be highly altered recrystallized quartzites.

A second case is the rock "northfieldite" described by B. K. Emerson¹⁷ from western Massachusetts, as a "band of contact quartz rock" which occurs around the margins and within a granite batholith in part gneissic, the Pelham granite. The rock occurs between the gneissic granite

and a highly metamorphosed series of sediments. Emerson bases his classification of it as an igneous rock only on the general distribution around the margins of the granite. He states that its coarser varieties resemble vein quartz, its finer a quartzite. His description of the mineralogy, textures and structures of the rock, and its conformable relations at places with the metamorphosed series of sediments, strongly suggest that this rock is a partially recrystallized quartzite. In fact Emerson himself states that "for a long time I considered the whole series including the . . . northfieldite to be sedimentary," but fails to state any reason for changing his opinion.

A rock which surrounds the Monson granite batholith, south of the Pelham mass, described by Emerson as a diorite, has been shown recently to have formed by the replacement of limestone.²⁰

Emerson later described another occurrence of "northfieldite."¹⁹ He finds the Milford granite in Massachusetts is "bordered by a zone of dark hornblendic quartz diorite, within which is another zone, about a mile wide, consisting mainly of fine grained, light colored aplite, much of it so poor in feldspar that it resembles a slightly biotitic quartzite." This is called "northfieldite." Emerson again bases his conclusion as to its igneous origin on its distribution as a concentric zone between the granite and the "hornblendic border zone." However, he states that "it is difficult to distinguish it either in the field or under the microscope from the nearby Algonkian quartzite." He also mentions the abundance of rutile needles in the quartz grains, a common characteristic of quartz of sedimentary rocks.²¹

It seems probable from a study of the descriptions that "northfieldite" is contact metamorphosed quartzite.

The third case cited by Tolman is that described by Derryhouse²² of a granite laccolith near Eskdale, England, which has a highly quartzose border phase in contact with volcanic rocks which it intrudes. The quartzose rock is transitional into the granite, but is fine grained at its outer margin and has a sharp contact with the volcanics. The interpretation of the quartzose rock as "an early phase of the granite and, therefore, an igneous rock" is based upon its areal distribution relative to the granite.

B. Simpson in a recent and more thorough study of the granite²³ finds there has been considerable assimilation of the country rocks and contaminated granite is common. He describes the presence of a fine grained micaceous quartzose rock, which at places is almost pure quartz, as parts of the margin and as irregular patches within the granite mass. At places he finds there is a sharp line between this rock and normal granite and at other places there is no sharp demarcation between the

two types. Though he agreed there were places where the granite is exceedingly fine grained and acid, he disagreed with Derryhouse's generalization that the granite becomes more acid as the margin is approached. Simpson is inconclusive regarding the origin of the acid rock.

Though Simpson concludes the granite is laccolithic in shape, the evidence he presents, as pointed out by S. E. Hollingsworth, in the discussion of the paper, would favor the view that the mass has the shape of a stock.

Since the origin of the quartzose rock has not been satisfactorily settled, and in view of the conflicting nature of the most recent descriptions of the rock, it is not considered that Tolman is justified on the basis of Derryhouse's description in classing this rock as a quartz mass grading into an igneous rock. Furthermore, it is significant that the rocks which underly the intruded volcanics are quartzose sandstones.²⁴ These are the oldest rocks exposed in the area. Since the granite may have the form of a stock, it is quite possible that the quartzose rock described above may be the partially assimilated quartzose sandstone left as recrystallized remnants in and at the margins of the granite.

QUARTZ VEINS GRADING INTO PEGMATITES

Tolman quotes the "silexite" masses described by W. J. Miller,²⁵ from the northern part of New York State as quartz masses of "igneous origin."

Miller applies the term "silexite" to "any body of pure or nearly pure quartz or silica of igneous or aqueo-igneous origin which occurs as a dike, segregation mass, or inclusion within or without its parent rock," and states "... the evidence that they are not true veins is decisive. None of them ever shows crustification and many of them grade into true pegmatite." The absence of crustification of course does not prove that the quartz has not been deposited from aqueous solutions, and no evidence is presented to support the view that these bodies are not ordinary quartz veins which in many cases grade into pegmatite dikes.

Tolman cites many cases of quartz which grade into pegmatite and feldspar-quartz masses. These and additional references are presented in the following list which is doubtless far from complete:

- C. R. Van Hise²⁶; Black Hills of South Dakota
- Adams and Barlow²⁷; Ontario
- P. Billingsley²⁸; Montana.
- L. H. Ogilvie²⁹; New York.
- J. F. Kemp³⁰; Atlantic Coast.
- H. C. Cooke³¹; Northern Ontario.

A. A. Pegau³²; Virginia.
 F. Zirkel³³; Pyrenees.
 H. Credner³⁴; Saxony.
 J. J. Sederholm³⁵; Finland.
 G. Klemm³⁶; Germany and the Alps.
 G. H. Williams³⁷; Maryland.
 J. E. Spurr³⁸; Alaska and Nevada.
 W. Cross³⁹; Colorado.
 A. C. Spencer⁴⁰; Wyoming.
 Spurr and Garrey⁴¹; Colorado.
 Lindgren and Ransome⁴²; Colorado.
 F. H. Lahee⁴³; Rhode Island.
 B. S. Butler⁴⁴; Utah.
 F. A. Thompson and S. M. Ballard⁴⁵; Idaho.
 J. S. Brown⁴⁶; Alabama.
 H. Rosenbusch⁴⁷; Ural Mountains.
 E. S. Bastin⁴⁸; Maine.

This relationship has been assumed to indicate an "igneous origin" for such quartz bodies. However, recent work by Schaller,⁴⁹ Hess,⁵⁰ Landes,⁵¹ Anderson,⁵² Wagner,⁵³ Derry⁵⁴ and others have shown that pegmatites form in large part by replacement from hydrothermal solutions, particularly the later stages which involve the deposition of minerals of the rare elements. Derry shows that quartz, one of the earliest minerals in the "complex pegmatites" of eastern Manitoba, is of the low temperature type and, therefore, most of the minerals have been deposited at comparatively low temperatures, at least below 575°C. He presents experimental evidence to show that there is little effect on the mutual lowering of melting points by any minerals present, all of which have high melting points, and concludes that the minerals must have been deposited from relatively weak aqueous solutions.

PEGMATITES GRADING INTO METALLIFEROUS QUARTZ VEINS

Tolman cites Spurr's description of the Silver Peak mines, where Spurr finds gold bearing veins grading into alaskite.⁵⁵ However, Tolman has failed to mention a paper by J. B. Hastings,⁵⁶ who examined the mines at a later date. Hastings presents evidence to show the quartz veins are deposited along sheared zones formed after the alaskite masses, and that the quartz veins do not pass transitionally into alaskite.

Three occurrences described by Butler,⁵⁷ Graton,⁵⁸ and Howitt,⁵⁹ of metalliferous quartz veins which grade into pegmatite are mentioned by Tolman. In discussing such transitions G. F. Loughlin and C. H. Behre, Jr.,⁶⁰ state that if any transitions between metalliferous veins and pegmatites have been proved, they are extremely rare. They state that, "The usual structural relations where metalliferous deposits of appreci-

able size are closely associated with pegmatites show that the metalliferous minerals, especially the sulphides, were introduced at a distinctly later stage than the pegmatitic quartz, by solutions derived from a deeper source than that of local quartz."

SUMMARY

Studies of the large quartz veins of Connecticut, Great Bear Lake, and elsewhere show that large quartz masses have formed by the action of hydrothermal solutions. The evidence regarding several large masses of quartz cited by Tolman as of "igneous origin" is inconclusive.

Large quartz masses formerly thought to grade into igneous rocks and to have formed from igneous melts are shown by recent work to be recrystallized quartzites. None of the other cases cited by Tolman of gradation of igneous rocks into quartz bodies seem entirely convincing, nor have any others been found in a search of the literature on quartz bodies.

Many examples of quartz bodies, only a few of them metalliferous, which grade into pegmatites, have been described. However, in view of the recent work which emphasizes the large part hydrothermal solutions play in the formation of pegmatites, it is evident that this relationship can no longer be considered to prove an "igneous origin" for the quartz bodies.

CONCLUSION

No occurrence of a body of quartz which has undoubtedly formed by the action of magmatic processes, that is by direct crystallization from an igneous magma, has been described in geologic literature.

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ON THE STAINING OF FELDSPATHOIDS, AND ON ZONAL STRUCTURE IN NEPHELINE

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I

The use of acids for distinguishing certain rock-forming minerals is older than the use of the microscope for this purpose. It has long been known that nepheline and a few other silicates are readily decomposed by acids, and that gelatinous silica is formed by the reaction. H. Behrens¹ seems to have been the first to suggest the idea of making the silica gel visible by impregnating it with dyestuff, but he gave no detailed account of his procedure. E. Boricky,² who devised many ingenious methods of microchemical analysis, used chlorine gas to decompose the silicates and stained the resulting silica gel with fuchsine solution. All the soda-feldspathoids and even olivine could be stained in this way, but not leucite. F. Zirkel³ describes briefly how the thin section is to be covered with a thin film of hydrochloric acid and then, after washing, immersed in a weak aqueous solution of fuchsine or methyl violet. Similar directions are given in other text-books, but often the instructions are so vague that one wonders whether the author ever practised the method himself or just related it at second hand. For instance, E. Weinschenk⁴ says the section that has been gelatinized by acid should be immersed "some hours" in congo-red or malachite green; yet anybody who has ever stained feldspathoids must know that it is not necessary to leave the preparation in the dye for more than a minute. Nobody seems to have given much attention to the effects produced by acids other than hydrochloric, or to the method of preserving the stained section as a permanent preparation. In order to make the fullest use of the staining method, these points deserve attention.

It is easy to satisfy oneself that liquid hydrochloric acid is not the most suitable acid for the purpose, because much of the silica goes into solution and is washed away. This difficulty can be overcome by exposing the rock section to the *fumes* of concentrated HCl instead of the liquid; excellent preparations can be made in this way, but it is difficult to restrict the action to a particular part of the section. Strong sulphuric acid and strong nitric acid are excluded because of their action on Canada balsam, and weak solutions of these acids are open to the same objection as hydrochloric acid. But a saturated solution of potassium bisulphate is a satisfactory reagent; it attacks nepheline and gives a thick gel in a few minutes. It has no action on leucite. A saturated solution of oxalic acid also dissolves nepheline but gives only a thin deposit of silica gel.

This acid acts slowly on leucite and forms enough gel, in 30 to 60 minutes, to take the stain quite deeply. It also acts on lime-rich plagioclase, though more slowly than on leucite.

The most useful reagent of all, for the soda-feldspathoids, is syrupy phosphoric acid (U. S. Pharmacopoeia, 85%). A thin film of the acid is spread with a glass rod over the part of the section which it is desired to stain. After about three minutes the slide is gently dipped in water to remove the acid and is then immersed in a weak solution (0.25% is sufficient) of methylene blue for about one minute. Nepheline, sodalite and analcime are stained deep blue by this treatment; melilite takes a lighter blue; leucite is not affected. After staining it is still possible to distinguish nepheline from sodalite or analcime by its birefringence. Other dyes may be used, for instance malachite green or methyl red; but the very soluble red dyes such as fuchsin and safranin are not suitable for making permanent preparations as they diffuse through the mounting medium.

After the section has been stained, the next problem is to preserve it. The procedure recommended by Weinschenk and others is to let it dry and then mount in xylol-balsam. This is quite unsatisfactory because in drying the silica gel shrinks, cracks, and breaks up to such an extent that the shape of the gelatinized grains may be lost. A simple way of overcoming this is to remove the section from the dye, dip it a few times in water to remove the excess of dye, and *immediately* put on a drop of ordinary liquid glue and a cover-slip. (I have used Dennison's glue and Le Page's glue, but any thick solution of glue in water would be suitable.) The glue should not be too watery or the dye will diffuse outwards and make the edges of the grains feathery. The glue dries quickly and the silica gel is fixed without shrinkage or disturbance. Preparations made in this way are quite transparent and will last for months in a moderately humid atmosphere; if a longer life is desired the cover-slip should be sealed with asphalt paint.

An alternative method, by which it is possible to cover the section with Canada balsam, takes advantage of the observation that the dyes named above, although insoluble in xylol, are soluble in a mixture of xylol and alcohol. After the section has been gelatinized, it is dipped in alcohol, then immersed in a solution of methylene-blue in equal parts of alcohol and xylol; after a minute it is dipped in pure xylol to remove the alcohol as well as the excess of dye, and then it is covered with a drop of xylol-balsam and a cover-slip. Although this method gives permanent preparations, they are not so perfect as those mounted in glue because some shrinkage can not be avoided.

When using the staining method to search for feldspathoids in a rock-

section, it is necessary to remember that zeolites are gelatinized too and that colloidal weathering-products of any kind will take up the dye. Thus it is useless to stain weathered rocks, and unless the rock is perfectly fresh it is unsafe to draw conclusions about the nature of a scanty interstitial material which takes the stain.

II

The presence of a zonal structure in nepheline crystals was recorded by E. Boricky⁵ in 1874, and a good example was figured from Waschholderberg near Teplitz. In 1926, F. Becke and J. E. Hibschr⁶ gave a careful description, with many drawings, of zonal nepheline crystals in the phonolites of Bilin and Brück, mentioning especially the Brüxer Schlossberg and Rudelsdorf. Most of these crystals show a core of normal refraction and birefringence followed by a narrow zone of weaker refraction and birefringence, and outside that a narrow mantle with higher refraction but weak birefringence. There may be an alternation of many such zones. The explanation offered by Becke and Hibschr was based on N. L. Bowen's⁷ study of the system nepheline-anorthite. Bowen showed that the presence of anorthite in solid solution causes the birefringence of nepheline to decrease to zero, after which it increases again with opposite sign. Becke and Hibschr concluded accordingly that the zoning described by them is a consequence of rhythmic variation in the anorthite content of the nepheline crystals, the zones of lower birefringence being those with more anorthite. O. H. Ödman⁸ in 1930 described zonal nepheline in rocks of Mt. Elgon, East Africa, and adopted the same explanation.

On applying the staining method described above to the phonolite of the Brüxer Schlossberg, I found that phosphoric acid has a selective action on the zoned nepheline crystals, the zones of lowest birefringence being almost unaffected while the rest of the crystal is deeply stained (Fig. 1). In a further series of tests I found that nepheline crystals which appear to be quite homogeneous in polarized light will sometimes exhibit a complicated zonal structure when stained by the phosphoric acid method. This was observed especially in the phonolite of Leeuwkraal, South Africa,⁹ and in a phonolite from Kenya which Bowen and Ellestad¹⁰ have described.

Since the zoning of nepheline may have any one of three explanations, namely presence of lime, presence of excess of potash, or presence of excess of silica (in other words, solid solution of anorthite, of kaliophilite, or of albite), it occurred to me that I might be able, by staining, to distinguish between these three possibilities. Fortunately for my purpose,

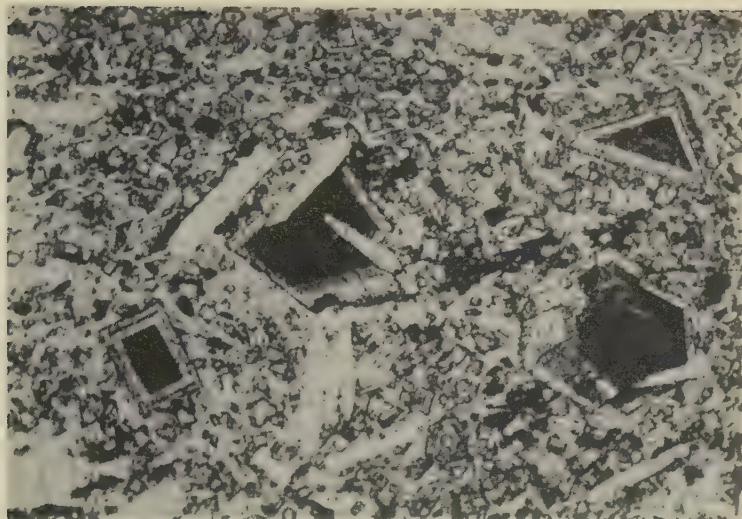


FIG. 1. Zonal nepheline crystals in the phonolite of the Brúxer Schlossberg, Bohemia, after staining with phosphoric acid and methylene blue. Magnification 50. Note tiny zoned nephelines in the groundmass.

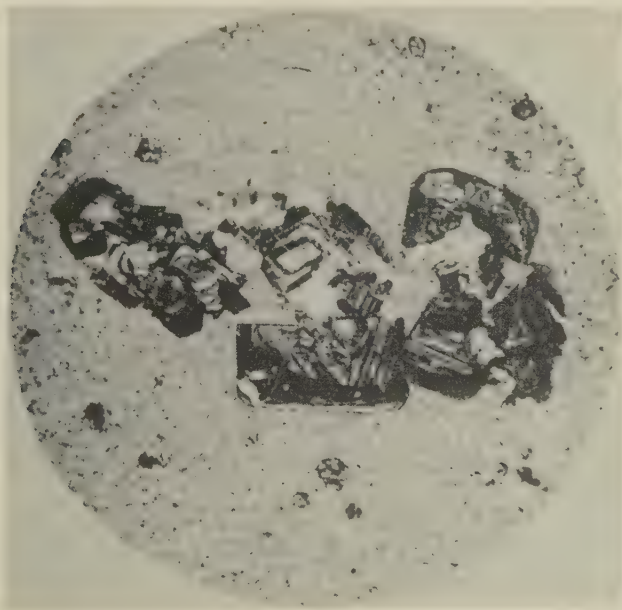


FIG. 2. Zonal nepheline crystals in the phonolite from Nyeri, Kenya, after staining. Before staining these crystals appeared to be homogeneous. Magnification 8.

Bowen and Ellestad¹⁰ have recently described and analyzed a potash-rich nepheline, in leucite-nephelinite from Lake Kivu; and an albite-rich nepheline, in phonolite from Kenya. Dr. Bowen was so kind as to lend me his specimens of these rocks for examination, and also to supply a specimen of synthetic nepheline containing 30% of anorthite. I had thin sections cut from these, and then stained them with phosphoric acid and methylene blue as described above. The results were as follows:—

- (1) The anorthite-rich nepheline, having the composition $\text{Ne}_{70}\text{An}_{30}$, was stained completely and deeply.
- (2) The potash-rich nepheline, having the composition $\text{Ne}_{57}\text{Kp}_{38}\text{An}_4\text{Ab}_1$, was stained completely and deeply, without any appearance of zoning.
- (3) The albite-rich nepheline, with the composition $\text{Ne}_{62}\text{Ab}_{21}\text{Kp}_{13}\text{An}_4$ developed a complicated system of stained and unstained zones (Fig. 2). In general the outermost zone was uncolored, as in the Bohemian phonolites.

It is clear, therefore, that neither anorthite nor kaliophilite is the cause of zoning in nepheline crystals, and that albite is the villain of the piece. More correctly expressed, the zoning of nepheline crystals is due to the rhythmic deposition of layers of nepheline-substance alternately richer and poorer in silica. All the rocks in which zonal nepheline has been observed contain much alkali-feldspar and have a relatively high silica content. The Kenya phonolite has 54.8% of silica; the Leeuwkraal phonolite 58.0%; and two analyses of Bohemian phonolites, quoted by Becke and Hibschi, show 55.8% and 56.5%, respectively. Only one of the latter is said to contain zonal nepheline, but it is rather likely that zoning would appear in the other too if it were stained. The nephelinite from Lake Kivu is free from feldspar and its silica content is only 37.7%; the nepheline in it is not zoned.

Unexpected confirmation of the conclusion stated above, regarding the cause of zoning, appeared when a section of the Schlossberg phonolite was exposed to the action of hydrochloric acid gas and then stained with methylene blue. The usual relation was now reversed, the outermost zones of the nepheline crystals taking the stain more deeply than the cores, presumably because a thicker film of silica was formed over the albite-rich zones.

I am indebted to Mr. E. N. Cameron and Mr. J. H. Cameron for making the excellent microphotographs which illustrate this paper.

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SHORTITE, A NEW CARBONATE OF SODIUM AND CALCIUM¹

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ABSTRACT

Crystals of shortite, named after Professor M. N. Short of the University of Arizona, were found in cores of clay shale from Sweetwater County, Wyoming, at depths between 1258 and 1805 feet. The crystals, several millimeters thick, are orthorhombic, hemimorphic, with the axial ratio $a:b:c=0.455:1:0.648$. The indices of refraction are: $\alpha=1.531$, $\beta=1.555$, $\gamma=1.570$, $2V$ is negative, 75° . Axial plane is $\{100\}$ with the c axis the acute bisectrix. Analyses of two types of crystals give the formula, $\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{CO}_2$.

INTRODUCTION

The mineral described in this paper, a double carbonate of sodium and calcium, $\text{Na}_2\text{CO}_3 \cdot 2\text{CaCO}_3$, was found in a drill core from the test well John Hay Jr. No. 1, located on Government land in the SE $\frac{1}{4}$ of the NW $\frac{1}{4}$, sec. 2 (1920 feet from N line and 2120 feet from the W line), T. 18 N., R. 110 W., about 20 miles west of the city of Green River, Sweetwater County, Wyoming. The well was drilled by the Mountain Fuel Supply Co. of Findlay, Ohio, operator, and made available to the U. S. Geological Survey for study by Mr. W. F. Nightingale, geologist, Mountain Fuel Supply Co. Drilling was started on Oct. 29, 1937, and completed on Jan. 3, 1938, at a depth of 5323 feet. The elevation is 6355 feet. Two samples from the core at depths of 1594 and 1600 feet, respectively, were sent to Mr. H. I. Smith, Chief, Mining Division, Conservation Branch, U. S. Geological Survey, in January, 1938, and shown on chemical analysis by R. C. Wells, of the Survey, to be nearly pure trona, $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$. Later other portions of the core, about 30 feet in all, were selected and sent to Washington by Mr. Smith for further study, which the writer began in May, 1939. In the course of this investigation numerous crystals of the new mineral shortite were discovered at several places in the core between the depths 1258 and 1805 feet.

Shortite is named in honor of Dr. Maxwell N. Short, Professor of optical mineralogy at the University of Arizona, President of the Mineralogical Society of America, and widely known for his contributions to the study of opaque minerals.

The writer wishes to express his thanks to Mr. M. L. Jefferson of the Bureau of Chemistry and Soils, Department of Agriculture, who determined that the crystals are pyroelectric, and to Dr. W. T. Schaller of

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the Geological Survey who has contributed the section on crystallography.

OCCURRENCE AND ASSOCIATION

The first appearance of shortite in the core is at a depth of 1258 feet. It occurs intermittently down to 1805 feet, which is the lowest section of the core sent to Washington. The matrix is a greenish-gray clay of the montmorillonite type which grades into oil shale. The clay and oil shale contain pyrite and carbonates of calcium and magnesium, the latter too fine-grained to determine whether the mineral is dolomite, or calcite and magnesite, or mixtures. Crystals of calcite up to two millimeters in diameter are abundant in places in the core. Massive trona is present at depths of 1325 feet and $1587\frac{1}{2}$ feet, but is not found associated with the new mineral. At the lower depth shortite is present in the clay that overlies the massive trona. The material is from the Green River formation of Eocene age. The nearly equant crystals of shortite are from 1 to 3 millimeters in size, while the tabular crystals are larger, up to 15 millimeters across and 2 to 3 millimeters thick.

CRYSTALLOGRAPHY

Shortite occurs in individual crystals, orthorhombic, hemimorphic, and simple in habit, being bounded essentially by only five faces, $a(100)$, $a'(\bar{1}00)$, $c(00\bar{1})$, $e(011)$, and $e'(0\bar{1}1)$ (Figs. 1 and 2). Narrow striated faces of $o\{01\bar{1}\}$, in oscillatory combination with the base $c\{00\bar{1}\}$, are usually present and line faces of $p\{111\}$ were measured on one crystal.

All the faces gave poor reflections. Measurements of $e \wedge e'$ averaged $65^\circ 53'$, hence $c=0.648$. The average measurements of four faces of $p\{111\}$, with the crystal set in polar position, gave $\phi=65^\circ 57'$, $\rho=57^\circ 21'$. The axial ratio is $a:b:c=0.455:1:0.648$, $p_0=1.425$.

The calculated angles are:

	ϕ	ρ
$c\{00\bar{1}\}$	$0^\circ 00'$	$90^\circ 00'$
$a\{100\}$	90 00	90 00
$e\{011\}$	0 00	32 57
$o\{01\bar{1}\}$	0 00	32 57
$p\{111\}$	65 33	57 26

Two general habits were observed: (1) Nearly equant to short prismatic with elongation parallel to the a -axis (Fig. 1) and tabular parallel to the macropinacoid $a\{100\}$ (Fig. 2).

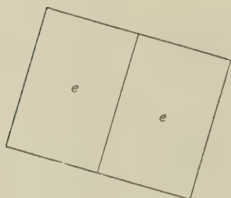


FIG. 1. Nearly equant crystal of shortite. Forms: $c\{001\}$, $a\{100\}$, $e\{011\}$.

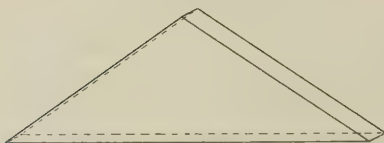


FIG. 2. Tabular crystal of shortite.

PHYSICAL PROPERTIES

The specific gravity of shortite, obtained by the pycnometer method at 25°C., is 2.629. There is a distinct cleavage parallel to the brachypinacoid $b\{010\}$, which has not been observed as a crystal form. It has a conchoidal fracture and vitreous luster. The hardness is 3. The crystals are strongly pyroelectric as determined by Mr. Jefferson using Martin's method.

Inversion takes place at about 200°C. accompanied by violent decrepitation. The resulting product appears to be a single compound rather than a mixture, though it is too fine-grained to permit such a conclusion definitely to be made. Incongruent melting takes place at about 600°C. The compound in the solid phase in this melt is probably calcium carbonate, with sodium carbonate, or the one to one sodium calcium carbonate, or a mixture of the two in the liquid phase. When cooled the

melt was so fine-grained that identification of the component parts by means of the petrographic microscope was not possible.

OPTICAL PROPERTIES

The color of shortite varies from colorless to a pale yellow in reflected light. In thin section the mineral is colorless. It fluoresces a light amber color in the ultra violet light from a high intensity mercury vapor lamp.

The indices of refraction at 25°C. are:

$$\left. \begin{array}{l} \alpha = 1.531 \\ \beta = 1.555 \\ \gamma = 1.570 \end{array} \right\} \pm 0.002$$

Computed from the indices of refraction the 2V angle (—) is 75°. The crystals are orthorhombic, with the optic axial plane parallel to the macropinacoid and the acute bisectrix normal to the base.

The optical orientation is:

$$\begin{array}{ll} X, \alpha \text{ (acute bisectrix)} & = c \text{ axis} \\ Y, \beta & = a \text{ axis} \\ Z, \gamma \text{ (obtuse bisectrix)} & = b \text{ axis} \end{array}$$

The dispersion is moderate $r < v$.

CHEMICAL PROPERTIES

Samples of shortite from depths of 1649 feet and 1729 feet were freed from the matrix by hand picking. At 1649 feet the matrix is oil shale. The crystals of shortite at this depth are predominantly equant to short prismatic in habit. Many of these crystals have small inclusions of pyrite. The matrix at 1729 feet is a clay of the montmorillonite type. Most of the crystals of shortite from this depth are thick tabular, parallel to the macropinacoid in habit. No pyrite was noticed in these crystals but a small quantity of clay was present.

The analyses of these two samples of shortite yield the formula: $\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{CO}_2$ or $\text{Na}_2\text{CO}_3 \cdot 2\text{CaCO}_3$.

ANALYSIS OF SHORTITE FROM DEPTH OF 1649 FEET.

	Per cent	Molecular ratios
CaO	36.34	0.6480
MgO	0.04	0.0010
Na ₂ O	19.91	0.3212
CO ₂	42.90	0.9750
Insol.	0.66	
	99.85	

ANALYSIS OF SHORTITE FROM DEPTH OF 1729 FEET

	Per cent	Molecular ratios
CaO	36.38	0.6487
MgO	0.04	0.0010
Na ₂ O	20.07	0.3238 0.3238=0.998
CO ₂	42.78	0.9723 0.9723=2.998
Insol.	0.68	
	<hr/> 99.95	

The insoluble material was determined by filtration on a sintered glass filter, drying at 105°C. for two hours and weighing.

Both samples were examined for the following components with negative results:

SO₃, Cl, F, SiO₂, metals of the R₂O₃ group, SrO, BaO, K₂O, Rb₂O, Cs₂O, Li₂O.

A sample composed of fragments of crystals of shortite that were free from traces of clay and pyrite was tested in a closed tube for water. None was present.

Shortite is slowly decomposed by cold water and more rapidly by boiling water. The sodium carbonate goes into solution and the calcium carbonate remains quantitatively in the solid phase.

The chemical synthesis of an anhydrous soda-lime carbonate with the composition of shortite has never been reported, though the compound Na₂O·CaO·2CO₂ is known. The writer hopes to study the paragenesis of the minerals found in this core. Such work may do much to reveal the conditions that prevailed during and since the deposition of these sediments.

NOTES AND NEWS

DISCUSSION OF "NOTES ON QUARTZ DIKES"

CARL TOLMAN, *Washington University, St. Louis, Missouri.*

Mr. Furnival, in his paper "Notes on quartz dikes" published in this issue of *The American Mineralogist*, summarizes pertinent data on large quartz masses.¹ He concludes that:

"No occurrence of a body of quartz which has undoubtedly formed by the action of magmatic processes, that is by direct crystallization from an igneous magma, has been described in geologic literature."²

Assuming that relatively pure quartz masses are meant, I am in complete agreement with this statement. However, in the repeated references made to an earlier paper by me on this subject,³ I consider that my views expressed in that paper have been seriously misinterpreted. I wish to take this opportunity to point out these misinterpretations because by them certain ideas, which I did not hold then and do not hold now, are incorrectly ascribed to the article.

The general impression conveyed by Furnival's paper is that I ascribed an igneous origin to pure or relatively pure quartz masses. This I was careful not to do for my belief was at that time, and always has been, that such igneous quartz masses did not exist. The aim of my paper as set forth in the introduction⁴ was to give the most objective review possible of the literature of "quartz masses *that are thought by the investigators or other persons* to be of igneous origin" with the object of ascertaining "if there are any features in their mineral composition or manner of occurrence that might be of diagnostic value in interpreting their origin." The first part of the foregoing quotation, with the exception of the words that I have italicized, was quoted by Furnival in the first sentence of his article. By the omission of the phrase "by the investigators and other persons" the incorrect implication is conveyed that the quartz masses reviewed were thought *by me* to be of igneous origin.

My ideas on the possible occurrence of quartz masses are adequately expressed, I think, in the following quotation from the second paragraph of my paper.⁵

¹ Furnival, G. W., Notes on quartz dikes: *Am. Mineral.*, **24**, 499-507 (1939).

² *Op. cit.*

³ Tolman, Carl, Quartz dikes: *Am. Mineral.*, **16**, 278-299 (1931).

⁴ *Op. cit.*, 278-279.

⁵ *Op. cit.*, 278

"It is obvious that a pure silica magma would not be possible. The melt would be of a highly viscous nature and would have a high temperature of consolidation, namely 1713°C. due to the lack of other constituents whose presence would cause a mutual lowering of the melting point. There is no evidence of such a high temperature at the time of emplacement."

May I also quote a parallel statement from the second paragraph of Mr. Furnival's paper.⁶

"Physical-chemical grounds alone seem to preclude the possibility of quartz masses forming by direct crystallization from a melt. Pure silica has a melting point of 1713°C. so that existence in nature of molten silica seems highly improbable, and even were it possible its high viscosity would make injection unlikely."

Thus the same idea is expressed in the two quotations, namely, that quartz masses resulting from the consolidation of a pure silica magma are highly improbable, if not impossible, and further I think that the quotation from my paper is the more emphatic about the matter. Yet no allusion to my expression of this generally held idea is given in Mr. Furnival's paper. Rather it is the implication of the first three paragraphs of Furnival's paper that I held a contrary idea.

Further, in my article, I do not point to a single quartz-rich mass described in the literature reviewed, that I considered to have been shown to be of direct igneous origin.

Yet Furnival⁷ discusses certain quartz masses that are discussed in my paper and states that I considered them "quartz dikes" (Foxdale, Isle of Man) or "of igneous origin" (Salem, India).⁸ Also, in his discussion of quartz masses described by Baumgartel, Furnival⁹ concludes that I was not justified in including them as "igneous quartz masses." It is true that, as my article was a critical review of the literature, I grouped them with some others that were considered by the *investigator concerned* to be igneous quartz masses. But in my discussion and in my conclusion, I stated repeatedly¹⁰ that I thought the evidence of an igneous origin for Baumgartel's quartz masses was inconclusive. These statements are ignored by Furnival.

Numerous quartz masses described in the literature by the authors of different articles reviewed as grading into pegmatite veins or dikes, or

⁶ *Op. cit.*, 499.

⁷ *Op. cit.*, 499.

⁸ *Op. cit.*, 287.

⁹ *Op. cit.*, 500.

¹⁰ *Op. cit.*, 295-297.

other related igneous rocks were discussed in my article. The opinions of each investigator as to hydrothermal or igneous origin of the quartz were given. Furnival¹¹ discusses some of the same occurrences and refers to a number of them as having been cited *by me* as of igneous origin. In this connection I quote from the concluding paragraph of the section of my paper concerned with these occurrence:¹²

"It seems, then, from the observational evidence available in the literature it must be taken as proved that quartz masses grade into pegmatites, aplites or like rocks which in turn grade into typical igneous rocks. But in arriving at this conclusion we have not in any way determined if any of the quartz masses represent the solidification of an igneous magma."

Furnival¹³ also cites certain large quartz masses, in South Africa, western Massachusetts, and Eskdale, England, that were discussed by me and concludes in his summary¹⁴ that:

"The evidence regarding large masses of quartz cited by Tolman as of igneous origin is inconclusive."

In my article I fail to find any statement that indicated that I considered such evidence anything other than inconclusive. Having admitted in the body of my paper that we do have pure quartz masses considered of hydrothermal origin and that we do have quartz-rich igneous rocks of one kind or another and, further, in accordance with prevailing petrologic conceptions the gap between these two occurrences would be bridged by quartz-rich bodies (supported by field evidence), the conclusions of my paper were concerned with *possible* features of these quartz rich bodies that *might* indicate an igneous origin.

¹¹ *Op. cit.*, 503.

¹² *Op. cit.*, 292-293.

¹³ *Op. cit.*, 501.

¹⁴ *Op. cit.*, 505.

TWO-CIRCLE GONIOMETERS

In view of the shortcomings (mechanical and optical) of several types of two-circle goniometers available abroad, a group of mineralogists and chemists are having such an instrument redesigned and built by a United States firm. This goniometer will have an interchangeable crystal carrier, to be used in x -ray work, and will serve the purpose of physicists and chemists, as well as mineralogists.

Valuable advice has already been obtained from various quarters. Anyone interested in this undertaking please communicate with one of the undersigned, who will gratefully receive comments and suggestions.

HARRY BERMAN, *Harvard University*,
Geological Museum; Oxford St.,
Cambridge, Mass.

J. D. H. DONNAY, *Université Laval*,
Faculté des Sciences, Blvd. de l'Entente,
Québec, P.Q.

OMISSIONS AND ERRATA IN THE AMERICAN
MINERALOGIST, VOLUME 23

CHARLES PALACHE, *Harvard University, Cambridge, Mass.*

I am indebted to the friendly interest of Dr. Schaller for calling my attention to a number of mistakes and omissions in papers that have been issued from this laboratory during the past year. In the following pages I am doing what I can to correct the errors or to supply the omissions. The notes all refer to articles appearing in Volume 23.

On page 645 in the list of forms of meyerhofferite, the forms $E\{212\}$ and $D\{2\bar{1}2\}$ should both be omitted from the table and indicated as doubtful, since each was observed but once.

On pages 714–716 the letters p and q of szomolnokite should be interchanged wherever used, both in tables and figures, so that p is $\{\bar{1}11\}$ and q is $\{111\}$. This is conformable to the original usage of Krenner.

On page 725 is given an angle table for pickeringite. By an unfortunate omission the table of observations on which the form list was based was omitted. It is given herewith. The form $S\{\bar{3}31\}$ should be omitted from the table and indicated as doubtful since it was observed but once. The angles given for the form $n\{210\}$ on line 4 of this table are wrong throughout and should read as follows:

ϕ	ρ	ϕ_2	$\rho_2 = B$	C	A
$66^\circ 44\frac{1}{2}'$	$90^\circ 00'$	$0^\circ 00'$	$66^\circ 44\frac{1}{2}'$	$83^\circ 58'$	$23^\circ 15\frac{1}{2}'$

MEASURED ANGLES OF PICKERINGITE

	Mean		Range		No. of	
	ϕ	ρ	ϕ	ρ	xls.	faces
010	0°10'	90°00'	0°03'—0°18'	—	4	6
100	90 20	90 00	90 08—90 32	—	2	2
110	49 18½	90 00	48 58—49 51	90°00'	11	15
210	66 45	90 00	66 38—66 52	90°00'	2	2
011	24 36	15 32	23 53—26 00	15°00'—15°51'	4	5
021	12 56	27 36	12 41—13 10	26 51—28 00	2	4
031	8 21	37 45	7 19—8 54	37 32—38 00	6	6
041	6 40	45 55	6 21—7 00	45 44—46 06	1	2
101	90 00	22 14	—	22 05—22 19	4	4
301	90 00	45 06	—	44 32—46 29	4	4
101	—90 00	10 30	—	10 00—10 30	2	2
301	—90 00	37 53	—	37 45—38 00	2	2
111	58 21	25 53½	57 42—58 50	25 37—26 12	4	6
221	54 18	41 15	53 37—54 48	41 02—41 34	5	5
111	—34 38	17 16½	—34 28—35 55	16 43—17 33	4	6
221	—43 18	35 09	—43 05—43 57	34 30—35 10	3	4
331	—45 25	47 30	—	—	1	1
121	38 25	33 14	38 18—38 43	33 09—33 17	3	4
131	28 20	41 00	27 42—28 55	40 23—41 34	7	10
121	—19 13	28 24	—19 00—19 25	28 10—28 35	3	3
131	—13 42	38 07	—13 23—14 22	38 00—38 16	5	5
141	—10 08	46 08	—10 05—10 11	46 06—46 09	2	2
211	70 15	37 03	69 41—71 20	36 51—37 42	4	6
231	42 27	46 10	42 05—42 51	46 06—46 20	8	10
211	—61 58	28 25	—61 52—62 05	28 10—28 38	2	3
231	—31 35	42 14½	—31 03—31 49	42 00—42 38	3	4
241	—25 14	48 16	—24 44—25 46	48 02—48 27	3	4
311	75 38	46 09	74 42—76 07	46 00—46 14	5	5
321	63 10½	48 21½	62 54—63 37	48 17—48 34	6	10
311	—72 05	39 07	—71 38—72 53	39 00—39 17	3	5
321	—56 33	42 51	—56 06—56 43	42 46—43 10	6	7
421	—64 22	49 42	—64 16—64 28	49 42—49 42	1	2

On page 750 is an angle table for botryogen. The list of observations was omitted also and is given herewith. The six new forms starred in this list are weak and should not be included in the angle table but should be indicated as requiring confirmation.

MEASURED ANGLES OF BOTRYOGEN (QUETENITE)

	Mean		Range		No. of	
	ϕ	ρ	ϕ	ρ	xls.	faces
001	—	—	Used for adjustment		11	11
010	0°00'	90°00'				
100	90 00	90 00				
*270	26 20	90 00	29°00'–31°06'	—	1	1
130	30 21	90 00			6	6
*250	34 52	90 00			2	2
120	40 51	90 00	39 35–40 58	—	8	10
350	46 27	90 00	46 03–47 06	—	3	3
450	56 00	90 00	54 09–56 51	—	4	4
110	59 58	90 00	58 57–60 18	—	10	13
210	73 50	90 00	73 41–74 00	—	2	2
011	24 09	23 37	23 56–24 26	23°36'–23°38'	3	3
021	12 51	39 19	12 46–13 03	39 06–39 41	3	3
*031	9 03	53 20	—	—	1	1
101	90 00	41 00	—	40 55–41 08	4	4
I01	–90 00	27 08	—	27 03–27 11	9	9
111	65 18	43 37	65 09–65 31	43 30–43 50	4	5
221	66 33	64 10	—	—	1	1
I11	–52 12	32 58	–51 56–52 29	32 56–33 00	3	3
*121	46 49	49 40	—	—	1	1
131	36 06	56 06	35 25–36 44	65 13–65 31	2	3
141	30 39	62 45	—	—	1	1
I21	–32 32	43 30	–30 56–32 39	43 23–43 38	5	7
*I31	–22 41	53 00	—	—	1	1
*I71	–11 44	70 50	–10 49–12 39	—	2	2

Another omission of the same nature was with regard to the mineral *parabutterite* described on page 743. Unfortunately, the data of observations for this mineral have been mislaid and have not as yet been discovered, so that this omission cannot now be supplied. In case the missing sheets are not found, the endeavor will be made to remeasure crystals of the substance and thus re-establish the elements and forms of the species on published data.

In partial explanation for these errors, it might be pointed out that the work on this paper was completed after the author had left Cambridge and some confusion arose in the manuscript material upon which it was based.

F. A. Bannister of the British Museum, Department of Mineralogy, has drawn my attention to two mistakes in an article on the *x*-ray study of diaphorite and freieslebenite by Horace Winchell. On page 834 the first space-group criterion should read:

hkl present only for $(h+k)$ even.

On page 835 the second space-group criterion should read:

$h0l$ present only for l even.

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

June 9, 1939

Dr. L. J. Spencer, President, in the chair.

The following were exhibited:—

- (1) A new electromagnetic separator. By Dr. R. C. Evans.
- (2) A selection of minerals from the Johnston-Lavis collection. By Dr. Malcolm MacGregor.

The following papers were read:—

- (1). *New refractometers employing diamond and other minerals.* By MR. B. W. ANDERSON, MR. C. J. PAYNE, and MR. J. PIKE. (With demonstration.)

Refractometers of the total reflection type are invaluable as a means for testing faceted gemstones. The range of these instruments is limited to refractive indices below that of the hemisphere or prism of the refractometer and by the liquid used to ensure optical contact. A new design of refractometer in which small prisms of diamond or blende replace the usual dense glass hemisphere has enabled the range to be considerably extended. If synthetic spinel is employed a very useful refractometer is obtained for reading lower refractive indices as the dispersion of this material is almost identical with that of the minerals commonly tested, and, accordingly, exact readings may be taken in white light.

- (2). *A new occurrence of kornerupine.* By MR. B. W. ANDERSON and MR. C. J. PAYNE.

Cut specimens of kornerupine have been encountered in mixed parcels of typical Ceylon stones. Confirmation of this new origin for the mineral was obtained by examination of a parcel of rough gem gravel sent direct from Ceylon from which two small pieces of kornerupine were recovered.

- (3). *The "baddelyite from Alnö"—an error.* By Dr. H. VON ECKERMANN.

E. Hussak in 1898 recorded the occurrence of baddelyite (ZrO_2) in the jacupirangitic varieties of the Alnö nepheline-syenites. A detailed study of these rocks has failed to confirm this, and no trace of zirconia could be detected. The anomalously birefringent melanite has, however, optical characters similar to those of baddelyite; and is suggested that the mineral described was really melanite.

- (4). *Crystal-structure of a natural nickel-iron alloy.* By Professor E. A. OWEN and Mr. B. D. BURNS. (Communicated by the President.)

The mineral "awaruite" from Grant's Pass, Oregon, consisting of a mixture of nickel-iron alloy with impurities, the chief of which is probably serpentine, has been examined by x-ray analysis. The alloy possesses a face-centered cubic structure, the lattice parameter of which is 3.5516 Å. It is not definitely decided whether the alloy conforms to the formula FeNi_2 or to the formula Fe_2Ni_3 , although the former is believed to be the more probable. The mineral contains by weight 26.50% iron, 60.42% nickel and 13.07% impurity. This gives 2.1 as the ratio of the number of nickel to the number of iron atoms present. Its density is 6.6 gm. per c.c., the density of the alloy being 8.5 gm. per c.c. The mineral contains 30 times its own volume of gas made up of a mixture of hydrogen and carbon monoxide in equal proportions.